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January-February 1934

THE EARTHQUAKE OF DECEMBER 20, 1932, AT CEDAR MOUNTAIN, NEVADA AND ITS BEARING ON THE GENESIS OF BASIN RANGE STRUCTURE[1]

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University of Nevada

AND

EUGENE CALLAGHAN
U.S. Geological Survey

ABSTRACT

This paper presents a summarized account of field studies of the rifts or faults formed at the time of the earthquake, interpretation of structural data, and relation to some structural features of the western part of the Great Basin and California. Sixty rifts occur in a belt 38 miles long and 4 to 9 miles wide in a valley between two groups of mountain ranges. Horizontal movement on individual rifts and the *en échelon* pattern of the entire group indicate that the major movement causing the earthquake was horizontal—the east side toward the south with reference to the west side. This direction of relative horizontal movement is the same as that on the east front of the Sierra Nevada at Owens Valley and on faults in California, including the San Andreas rift. It is suggested, therefore, that movements in the western part of the Great Basin and California are definitely related. The rift area lies on the boundary between those ranges trending dominantly to the north and northeast and those ranges trending dominantly to the northwest. This line does not appear to have been pointed out previously, and it may be a tectonic line corresponding in some respects to the east front of the Sierra Nevada and the San Andreas rift.

INTRODUCTION

Field investigations of those places in the Great Basin where major earthquakes have originated are a source of pertinent infor-

[1] Published by permission of the Director, U.S. Geological Survey. This paper was presented before the Sixteenth International Geological Congress at Washington, D.C., July 26, 1933.

mation concerning the nature and relative direction of earth movements taking place at the present time. They also furnish a clue to the nature of the movements that produced many of the characteristic features of the Basin and Range Province. This is certainly true of the studies of the Owens Valley earthquake of 1872 and the Pleasant Valley earthquake of 1915. The faults formed in 1872 in Owens Valley are numerous and discontinuous, though largely concentrated along the base of the Alabama Hills. They reveal both horizontal and vertical movements. The faults formed at Pleasant Valley occur along the west base of the Sonoma Range and reveal vertical movement only. The faults formed at the time of the Cedar Mountain earthquake are distributed *en échelon* through a valley, indicating relative horizontal movement of the adjoining mountain blocks—the east side toward the south. This indicated direction of relative horizontal movement corresponds to similar movements at Owens Valley and on the San Andreas rift. It is the purpose of this study to point out the structural features of the epicentral area of the Cedar Mountain earthquake and their possible significance in reference to Basin Range structure.

THE EARTHQUAKE

On December 20, 1932, an earthquake of major intensity originated near Mina in the area east of Gabbs Valley Range and Pilot Mountains in the southwest central part of Nevada. It was definitely perceptible over an area of about 400,000 square miles, including Nevada and parts of California, Oregon, Idaho, Utah, and Arizona. A circle including the scattered outermost points reporting perceptible shock has an area of nearly 1,000,000 square miles.

It is remarkable, therefore, that no lives were lost, and that damage was confined to demolition of a stone and an adobe cabin, broken chimneys and crockery, injury to mines and ore-treating plants, and minor items. This is to be explained in part by the sparse population, lack of water-soaked alluvium, and probable great depth of origin. Geological effects included change in flow of springs, avalanches of boulders down steep slopes, churning of surface soil in places, and upthrown boulders in at least one place.

The isoseismal lines VI, VII, VIII, and IX, according to the Rossi-Forel scale, are elongate in a northwest-southeast direction approxi-

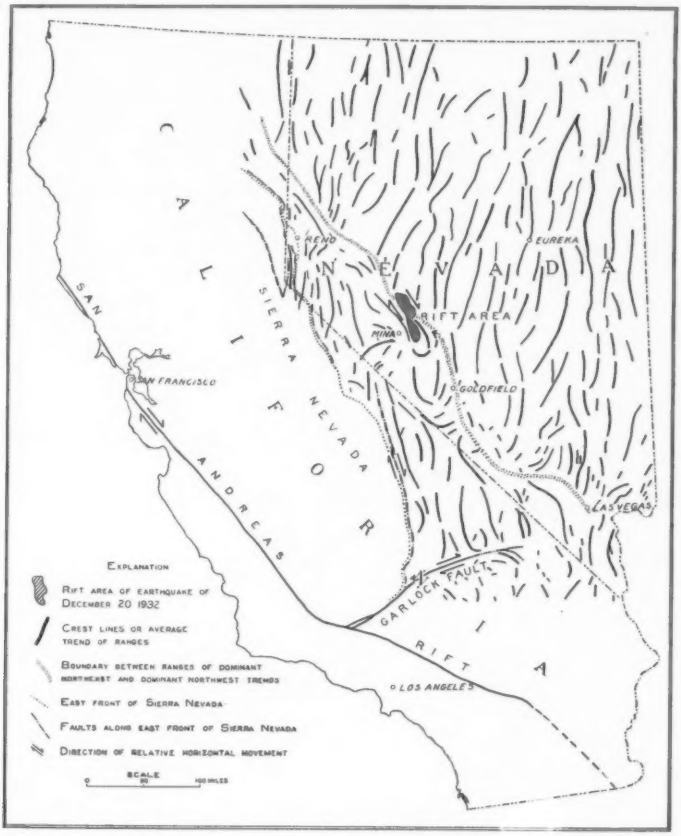

FIG. 1.—Map showing the location of the epicentral or rift area and its relation to some structural features of the western part of the Great Basin and California.

mately along the line shown in Figure 1. The intensity of the shock within the epicentral area was between IX and X. It appears that the strength of the shock varied considerably from place to place in the epicentral area. In places the surface of the

ground appeared to have been violently agitated, whereas in other places there was no evidence that it was disturbed.

Aftershocks are to be numbered in the thousands and were reported to be still continuing on January 9, 1934, though at greatly reduced intensity and frequency. Many of the aftershocks were sufficiently strong to be felt over a considerable area outside the epicentral region. Rumbling sounds accompanied most of the perceptible aftershocks, and sounds unaccompanied by perceptible shocks were heard. It was observed that aftershocks felt and heard at one point in the epicentral area were not perceived at other points, thus indicating that aftershocks originated at various points within the mass of rock affected by the movement. According to Dr. Gutenberg[2] epicenters of aftershocks are as much as 100 miles apart in a north-south direction.

THE RIFT AREA

TOPOGRAPHIC AND GEOLOGIC FEATURES

The rift area or epicentral area of the earthquake occupies a partly dissected lowland or valley lying between the rugged and essentially continuous mass of the Gabbs Valley Range and Pilot Mountains on the west and the somewhat more subdued Paradise Range and Cedar Mountain on the east, as shown by the map (Fig. 2). It should be emphasized that the elongate valley is not floored with alluvium of great depth as is generally regarded as characteristic of valleys in the Great Basin, but that bed rock occurs at or near the surface over the entire area with the exception of the playas at either end and some small fans.

The Gabbs Valley Range and Pilot Mountains have a curving trend to the northwest. The highest point is Pilot Peak (9,207 feet), which is over 3,000 feet above the valley containing the rifts. The eastern front is quite irregular.

Cedar Mountain is much smaller and more subdued than its western neighbor and trends more to the northwest, especially at the north end. The higher peaks rise scarcely 1,000 feet above the pediment slopes.

Paradise Range trends to the north and northeast. The eastern

[2] Beno Gutenberg, Personal communication.

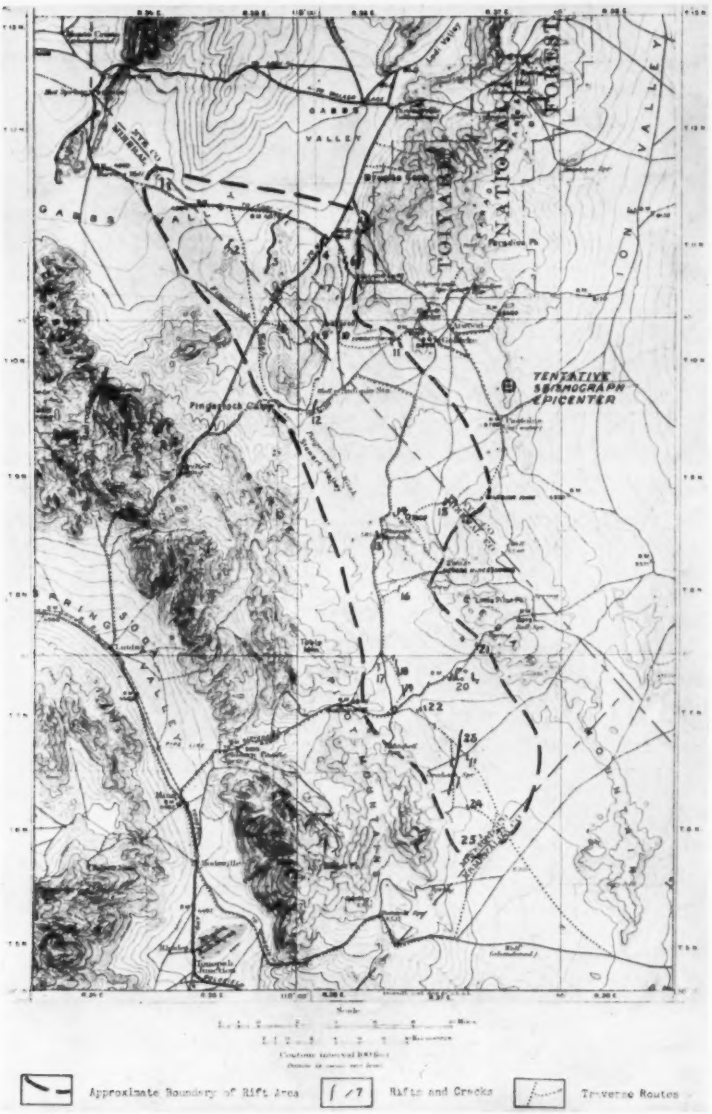

FIG. 2.—Topographic map of rift area and vicinity showing location of rifts and traverses. Topographic base from Hawthorne and Tonopah quadrangles of the U.S. Geological Survey.

slope is moderately gentle and the summit area rather subdued, but the western slope is abrupt and deeply furrowed. Paradise Range and Cedar Mountain are connected by a narrow ridge of volcanic rock.

The lowland between the two mountain masses trends to the northwest parallel to the western mountain mass and comprises two drainage systems, one (Fingerrock Wash) sloping toward the northwest and having its terminus in Gabbs Valley (4,262 feet) and the other, much smaller, sloping toward the southeast and ending in a playa (5,301 feet). The altitude of the divide between the two is about 6,200 feet. The open character of the lowland is interrupted by a row of low hills branching from the Gabbs Valley Range at Fingerrock Camp. The part of the lowland north of the wash east of Fingerrock Camp is characterized by ridges of volcanic rock which have a northerly trend and are separated by valley slopes which are dissected in some places. South of that line the lowland is characterized by long pediment slopes inclined toward the center of the valley. They have been partly dissected, especially within the Fingerrock Wash drainage. Small hills and ridges, many of them trending to the north or northeast, rise above the general surface of the pediment slopes and are more readily differentiated in the southeastward drainage because of the lesser degree of dissection.

The geology of the rift area and adjoining mountain ranges has been treated in a number of reports[3] mostly dealing with special phases of geologic investigation. The literature cited, together with personal observations of the writers, leads to the following general-

[3] J. P. Buwalda, "Tertiary Mammal Beds of Stewart and Ione Valleys in West-Central Nevada," *Univ. Calif. Dept. Geol. Bull.*, Vol. VIII (1914), pp. 335–63; Adolph Knopf, "Ore Deposits of Cedar Mountain, Mineral County, Nevada," *U.S. Geol. Surv. Bull. 725* (1922), pp. 361–82; C. W. Clark, "Geology and Ore Deposits of the Santa Fe District, Mineral County, Nevada," *Univ. Calif. Dept. Geol. Sci. Bull.*, Vol. XIV (1922), pp. 1–74; H. G. Ferguson and S. H. Cathcart, "Major Structural Features of Some Western Nevada Ranges (abstract)," *Jour. Wash. Acad. Sci.*, Vol. XIV (1924), pp. 376–79; H. G. Ferguson, "Late Tertiary and Pleistocene Faulting in Western Nevada (abstract)," *Bull. Geol. Soc. Amer.*, Vol. XXXVII (1926), p. 164; "The Gilbert District, Nevada," *U.S. Geol. Surv. Bull. 795* (1927), pp. 125–45; W. F. Foshag, "Quicksilver Deposits of the Pilot Mountains, Mineral County, Nevada," *ibid., Bull. 795* (1927), pp. 113–23; Eugene Callaghan, "Brucite Deposit, Paradise Range, Nevada; A Preliminary Report," *Univ. Nev. Bull.*, Vol. XXVII (1933), p. 1–34.

izations concerning the geology of this region. The mountain ranges are composed chiefly of Triassic sediments and volcanic rocks with some Jurassic sediments which have been intruded by granodiorite and related rocks probably corresponding in age to the granodiorites of the Sierra Nevada. Older rocks have been noted in the Gilbert district[4] and elsewhere.[5] Tertiary volcanic rocks occur in the ranges as faulted-in segments and caps. The pre-Tertiary structure of the ranges is complex.

The valley or lowland that contains the rifts consists largely of low hills and elongate ridges of volcanic rock and partly dissected old alluvial fans or lake beds north of the wash between Pactolus and Fingerrock Camp. South of this line the lowland is almost wholly underlain by Esmeralda (Miocene) lake beds with some associated volcanic rocks. According to Buwalda,[6] the Esmeralda formation consists of thin-bedded sandstones, shales, limestones, and volcanic ash beds which have been moderately folded with axes roughly parallel to the trends of the ranges. Furthermore, the whole belt between the mountain ranges has been warped into a broad syncline. The abundance of faults in these beds was recognized by Knopf[7] and Ferguson and Cathcart.[8] Subsequent to the major deformation the lake beds were graded to gently sloping or pediment surfaces on which was deposited a mantle of gravel usually 5 to 25 feet thick.[9] This old surface has been dissected to depths of several hundred feet in the Fingerrock drainage system, but only a few feet in the area of southeasterly drainage. The writers noted many breaks and offsets in the old surface, which were probably produced by faulting after the development of the pediment surface. Many of the rifts formed during the December earthquake occur along these breaks in slope.

GENERAL FEATURES OF THE RIFTS

The term "rift" is used in this discussion to signifiy a unit zone of rupture as it is observed at the surface. A rift is composed of an

[4] Ferguson, "The Gilbert District, Nevada," *op. cit.*, p. 130.

[5] Ferguson and Cathcart, *op. cit.*, p. 377.

[6] *Op. cit.*, pp. 344–50.

[7] *Op. cit.*, p. 361.

[8] *Op. cit.*, pp. 376–79.

[9] Buwalda, *op. cit.*, pp. 352–53.

aggregate of fissures which may or may not show displacement of opposite sides (Figs. 3, 4, 5, 6). The dimensions of the rifts range from a few hundred feet to 4 miles in length and from a fraction of an inch to 400 feet in width. In all, 60 rifts, both large and small, were observed. The term "fissure" is used to signify a single elongate opening or crack in the surface of the ground. The length may range from a few inches to several hundred feet, and the width is generally less than a foot. The term "graben" is used to signify an elongate block of ground dropped between two fissures (Fig. 5).

It should be strongly emphasized that the rifts are primary features caused by actual shifts of adjacent rock masses rather than secondary fissures in alluvium, such as have been prominent in many earthquake areas.[10] The rifts occur in rock in many places at the surface. They follow or cross rock ridges and die out in alluvium. A few secondary cracks appear in alluvium, and some were noted at the head of some of the fans parallel to a radius of the fan.

The distribution of the rifts is shown by the map (Fig. 2). They occupy a belt 4 to 9 miles in width, extending from a point 3.6 miles east of Warrens Well in Gabbs Valley southeasterly 38 miles to a point 8 miles east of Pilot Peak. Undoubtedly there are rifts within the blank area within this belt, but conditions did not permit their discovery and mapping. A few fissures were found outside this area near the springs on the west side of the Pilot Mountains and at Black Spring, 11.2 miles east of Simon (Nevada mine on map). The trends of these fissures correspond to those of the rifts in the rift area. Over half of the rifts were found to lie at the foot of a break in a west or northwest facing slope, through at least part of their length.

The *en échelon* pattern of the rifts is shown on the map (Fig. 2) and emphasized in the diagram (Fig. 7). They may be segregated in the following groups on the basis of their average trends, as shown in Figure 8. Thirty rifts, both large and small, that range between north-south and N. 28° E., have an average trend of N. 11° E. Nine

[10] R. D. Oldham, "Report on the Great Earthquake of 12th June, 1897," *India Geol. Surv. Mem.*, Vol. XXIX (1899), pp. 85–111; State Earthquake Investigation Commission, "The California Earthquake of April 18, 1906," *Carnegie Inst. Wash. Pub. No. 87*, Vol. I, Part 2 (1908), pp. 401–2; Charles Davison, *The Japanese Earthquake of 1923* (London: Thomas Murby & Co., 1931), p. 108.

FIG. 3.—Rift No. 4 at point 900 feet south of Twin Leads shaft in northern part of rift area. View north. The strong fissure is in the direction of the rift which traverses the low gap in the middle distance. Downthrow side at left. Note tendency of small fissures to trend to the northeast of the direction of the rift. The opening is due to caving as the true width of the fissure is about 2 inches.

FIG. 4.—Fault scarp 18 inches high crossing low hill composed of Esmeralda formation. One of the many fissures composing the large rift (No. 23) east of the Pilot Mountains. View northeast.

FIG. 5.—Graben 13 feet wide in rift No. 4 at a point 3,700 feet south of Luning road. View north. The right (east) side shows a vertical displacement of 8 inches and the left side 2½ inches. Low hills of Tertiary volcanic rock in middle distance and Gabbs Valley beyond.

FIG. 6.—Open fissure and compression ridge (at hammer) in rift No. 18 in the central part of the rift area. The open fissure trends N. 18° E., whereas the compression ridge is at right angles. This condition indicates a southward shift of the east (right) side with respect to the west side.

small rifts that range from N. 45° E. to N. 83° E., have an average trend of N. 61° E. Sixteen rifts, both large and small, that range from N. 5° W. to N. 25° W., have an average trend of N. 11° W. Consequently, the average trends of all three groups of rifts lie to the

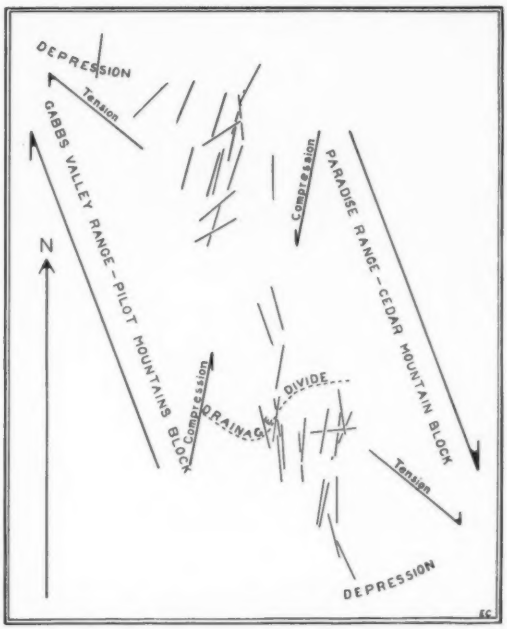

FIG. 7.—Diagram showing the average trends of the majority of the rifts in their relative mapped positions and their relation to the main topographic features and to a possible arrangement of stress that might have produced them. The direction of compression is taken as the average direction of the majority of the rifts (N. 11° E.). The forces producing the compression may be represented as a southward shift of the Paradise Range–Cedar Mountain block with reference to the mountain block to the west.

east of the direction of the axis of the rift area, which is approximately N. 21° W. Some of the rifts, particularly No. 4 (Fig. 9), show a tendency toward a sigmoid form with the north end trending more to the northeast and the south end trending more toward the southwest than the direction of the main part of the rift. Sharp turns

and zigzags are common features of most of the rifts and are particularly well shown in No. 4.

The arrangement of the fissures composing the rifts is shown in Figure 9, and in more detail in Figure 10. In general, a long, strong

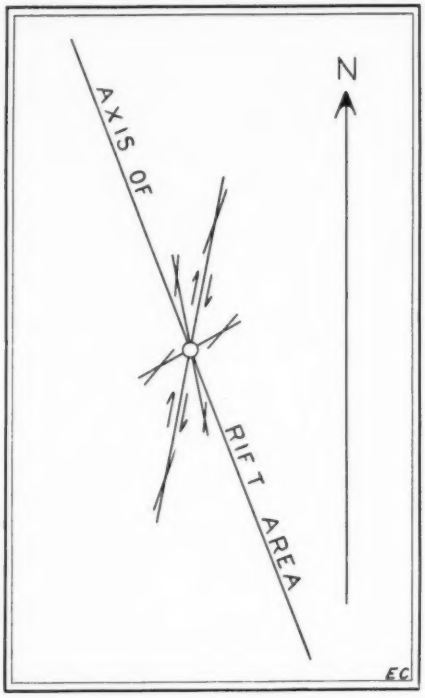

FIG. 8.—Diagram showing the relation of the average trends of the three main groups of rifts to the axis of the rift area. The superimposed short lines represent the trends of the *en échelon* fissures and the arrows the relative horizontal movement for all three groups.

fissure is in the direction of the rift, but short weak fissures are at an angle, usually from 5° to 40°, to the direction of the rift. Consequently, most of them form an *en échelon* belt, and this arrangement is strikingly uniform for nearly all the rifts observed, both large and small. The trend of the individual fissures *en échelon* is to the north-

east of the direction of the rift, except in those places where the rift trends to the northeast in excess of 35°. This pattern agrees with patterns of fissures along the San Andreas rift.[11] So far as could be

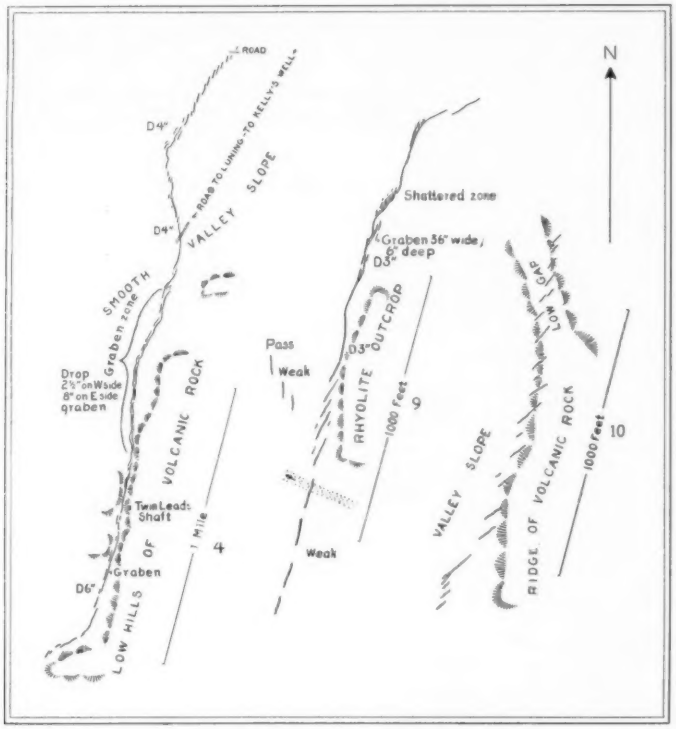

FIG. 9.—Some typical rifts formed at time of Cedar Mountain earthquake. Sketches from pace traverses. The numbers correspond to those on the topographic map. The scale is given beside each sketch. Note the pattern of the fissures composing the rifts, the displacements, and the relation of the rifts to topographic features and bed rock. *D* indicates downthrow side.

determined, all the fissures are essentially vertical, with the possible exception of the west wall of the graben near the south end of the

[11] G. K. Gilbert, "Studies of Basin Range Structure," *U.S. Geol. Surv. Prof. Paper 153* (1928), p. 13.

large No. 23 rift, which appears to dip to the east. Reversals of throw were noted on a number of the fissures and one is shown in the northeast corner of Figure 10. Overlapping of fissures forming the

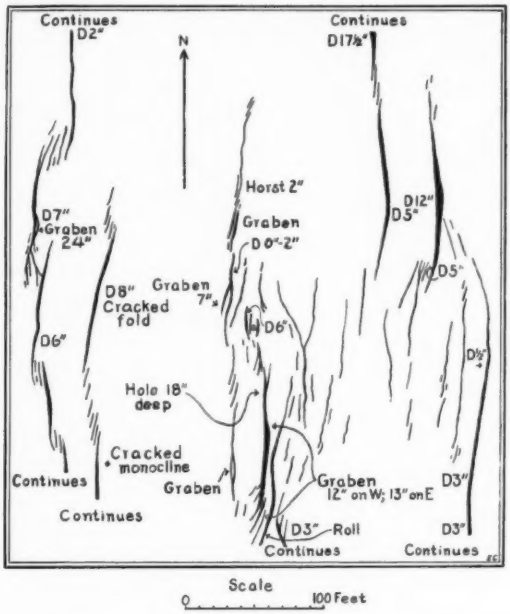

FIG. 10.—Sketch from pace traverses showing the pattern of fissures within a single rift zone (No. 23) which is here a graben. At this point the rift trends north-south, and the fissures at either side represent the limits of the rift in an east-west direction. The weight of line indicates the relative strength of the fissures. *D* represents the downthrow side. Many features of the rifts are illustrated—including discontinuity of fissures, *en échelon* zones of weak fissure between strong fissures, overlapping, two types of grabens (south, center), and reversal of throw on the same fissure (northeast corner).

west wall of the No. 23 rift is well shown in Figure 10. The change from one strong fissure to another is generally accomplished in an *en échelon* zone, as shown in Figure 10.

Vertical displacement is revealed by nearly all the major rifts (Fig. 4). It may be shown on a single strong fissure with no apparent displacement on weak intervening fissures, or intervening fissures

may show distributed displacement (Fig. 10). The direction of throw is generally down the topographic slope. Consequently, the direction of throw is nearly equally divided among all the rifts. The westernmost rift of the No. 9 group (Fig. 9) shows the uphill side dropped to the east. Not considering the subsidence of grabens, the amount of throw is generally less than 7 inches, except in No. 23, where the throw may be as much as 2 feet.

Horizontal displacement was recognized in rift No. 18, two rifts in the No. 20 group, and part of the large rift in No. 23. The first three show compression ridges on those parts of the fissure which zigzag toward the northwest, as shown in Figure 6. Fissures trending northeast are open or even contain grabens. One of the fissures in rift No. 23 shows a horizontal displacement of 34 inches and a vertical displacement of 5 inches. In every place where horizontal displacement was recognized the indications are that the east side has moved south with respect to the west side. This direction of movement is also confirmed by the *en échelon* pattern of the fissures in both the rifts that show horizontal displacement and those in which it is not perceptible.

Grabens occur in nearly all the major rifts (Figs. 5 and 10). Most of them are less than 20 feet wide and less than 100 feet in length. Wide grabens are generally not more than a foot in depth. The large rift in No. 23 is exceptional in all these respects for at one point the graben is over 100 feet wide with the west wall about 4 feet high and the east wall about 2 feet high. The bounding fissures may join at either end and produce a graben of lenticular form, or there may be no bounding fissures at the ends so that a longitudinal profile approaches a catenary curve. Both conditions are shown in Figure 10.

Compression ridges occur on a few of the fissures that show definite horizontal movement. One ridge on rift No. 23 is about 11 feet wide and $1\frac{1}{2}$ feet high. They appear to be largely indicative of horizontal movement.

No evidence of regional tilt of the earth has yet been found. One line of levels across the area has recently been redetermined by the United States Coast and Geodetic Survey, but results are not yet available.

ORIGIN OF THE RIFTS

The field data reveal two principal features that bear on the direction of the movements producing the system of rifts and, incidentally, the earthquake. First, the rift area is a belt of *en échelon* transverse faults or rifts in a lowland of Tertiary lake beds and volcanic rocks lying between two mountain range blocks. Second, the *en échelon* pattern of the fissures making up many of the rifts as well as the actual horizontal movement along some of the rifts indicate a relative horizontal movement of the east side toward the south. The significance of this fact is emphasized by the uniformity of these features in all the major rifts observed. Undoubtedly there are multitudes of old faults[12] in the area along which no movement occurred during the earthquake. It may therefore be assumed that movement occurred only on those faults which happened to be in the proper position to move according to the directions of the forces applied to them. Consequently, the pattern of the rifts and the actual movements along them should give a clue to the possible directions of the forces applied.

The origin of *en échelon* faults has been treated by a number of writers, and has been summed up by Nevin.[13] Chamberlin[14] describes a belt of *en échelon* faults near Billings, Montana, which is some 56 miles long and trends N. 78° W. It consists of separate faults that trend approximately 45° farther to the northeast than the direction of the belt and lie between two domes, one at the northwest side and the other at the southeast. Chamberlin concludes that the *en échelon* faults were caused by an eastward movement of the mass south of the faults with respect to that to the north, "together with local torsion and incidental tension developed by the doming process."[15] Fath[16] describes the belts of *en échelon* faults in Oklahoma

[12] Ferguson and Cathcart, *op. cit.*, pp. 376–79.

[13] C. M. Nevin, *Principles of Structural Geology* (New York: John Wiley & Sons, Inc., 1931), pp. 104–6.

[14] R. T. Chamberlin, "A Peculiar Belt of Oblique Faulting," *Jour. Geol.*, Vol. XXVII (1919), pp. 602–13.

[15] *Ibid.*, p. 613.

[16] A. E. Fath, "The Origin of the Faults, Anticlines, and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U.S. Geol. Surv. Prof. Paper 128* (1921), pp. 77–80.

which trend nearly north-south with individual faults approximately N. 45° W., and concludes that they have been formed by horizontal movements along zones of weakness in the pre-Cambrian basement which are reflected at the surface in *en échelon* tears. Sherrill[17] holds that the *en échelon* faults of Oklahoma could have been produced by torsion brought about by regional tilting or steepening of the surface. This is shown diagrammatically by Nevin.[18] Willis[19] regards the *en échelon* Mexia fault zone in Texas as produced by horizontal movement. Gilbert[20] shows the pattern of fissures and the relative horizontal movement on the San Andreas rift at the time of the California earthquake of April 18, 1906. The fissures are inclined toward the direction of pressure. Willis[21] shows a similar pattern of gash veins *en échelon* in which the veins are inclined toward the direction of pressure.

It seems wholly probable in view of the explanations for *en échelon* faults offered by the writers cited above that the belt of *en échelon* rifts at Cedar Mountain may be expressed in a resolution of forces, as shown in Figure 7; in brief, a southward or southeastward shift of the Paradise Range–Cedar Mountain block on the east with reference to the Gabbs Valley Range–Pilot Mountains block on the west. This is indicated not only by the pattern of the rifts within the rift area, but by southward movements of the east sides of the individual rifts shown both in the *en échelon* pattern of the fissures composing the rifts and the actual horizontal displacements. The rifts are not so regular as those described in the references cited, nor do they lie at an average angle of 45° to the axis of the rift area. It seems that at least part of this difference may be ascribed to the complexity of geologic structure and rock types in the Cedar Mountain area. No definite evidence of absolute movement is at hand.

[17] R. E. Sherrill, "Origin of the *en Échelon* Faults in North-Central Oklahoma," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XIII (1929), pp. 31–37.

[18] *Op. cit.*, p. 105.

[19] Bailey Willis and Robin Willis, *Geologic Structures* (New York: McGraw-Hill Book Co., Inc., 1929), pp. 285–86.

[20] *Op. cit.*, p. 13.

[21] Bailey Willis, *Geologic Structures* (New York: McGraw-Hill Book Co., Inc., 1923), pp. 178–79.

The possibility of torsion should be considered in view of the conclusions of Sherrill.[22] The rift area is a topographic arch with a depression at either end. The drainage channels are intrenching themselves in what was formerly a graded surface,[23] indicating that there has been differential uplift. The uniform indication, however, of horizontal movement throughout the rift area on individual rifts is not readily accounted for by the torsion hypothesis, so that it appears that the hypothesis of horizontal movement of the mountain blocks best fits the field data.

It should be clearly understood that this explanation of the movements involved in the formation of the rifts is derived wholly from the study of the rifts and associated features. It is hoped that studies of seismologic records may furnish evidence that will bear on the explanation given above. It is realized that a detailed analysis of the structure of the rift area and a large part of the surrounding region might lead to different conclusions. The explanation of the rifts given here, however, seems plausible in view of the data at hand.

BEARING ON BASIN RANGE STRUCTURE[24]

Two results of the field study of the Cedar Mountain earthquake seem to have a bearing on Basin Range structure. First, a large part of the rift area is located on the boundary (Fig. 1) between the area containing those ranges which trend dominantly to the north and northeast and the area of ranges which trend dominantly in a northwesterly direction. The first area lies to the east of the second. Second, the relative movement of the mountain blocks seems to have been horizontal rather than vertical and corresponds in direction to horizontal movements in Owens Valley and on the San Andreas rift.

The belt of valleys that marks the change from dominantly northwesterly to dominantly north or northeasterly trends seems to have attracted little attention. Reference to Figure 1 or to topographic maps will show that this boundary is not sharply marked at all

[22] *Op. cit.*, pp. 31–37.

[23] Buwalda, *op. cit.*, pp. 355–58.

[24] Callaghan accepts full responsibility for the statements made under this heading.

points. Spurr[25] alludes to it very briefly. Longwell[26] regards the Las Vegas Valley, which is a part of this belt, as possibly an important fault zone as thrusts in adjacent ranges do not continue across and strikes differ. Hewett[27] regards it as the eastern boundary of the area of late Tertiary overthrusting from the west. This area is bounded on the south by the Garlock fault,[28] but its northern limit is as yet undetermined. No late Tertiary overthrusts have been reported in the Cedar Mountain area. Recent fault scarps occur on both sides of this belt. All have been regarded as normal faults with vertical throw except a part of the faults in the Owens Valley area[29] and the rift area herein described. There appears to be no significance in the direction of throw, for the Pleasant Valley[30] fault is on the west side of the Sonoma Range, whereas another fault described by Ferguson on the same side of this belt lies on the east side of the Toyabe Range.[31] Consequently, the true significance of the boundary between the two areas of differing trend of ranges in west-central Nevada remains to be demonstrated. Its great length and continuity suggests that it may be a structural line comparable to the east front of the Sierras and the San Andreas rift, which it roughly parallels. Possibly the evidence for horizontal movement in the Cedar Mountain area gives a clue as to the kind of movement that may characterize this zone, but the rift area represents scarcely a tenth of the probable length of the zone and does not lie wholly

[25] J. E. Spurr, "Origin and Structure of the Basin Ranges," *Bull. Geol. Soc. Amer.*, Vol. XII (1901), p. 258.

[26] C. R. Longwell, "Structional Studies in Southe n Nevada and Western Arizona," *Bull. Geol. Soc. Amer.*, Vol. XXXVII (1926), p. 573.

[27] D. F. Hewett, Personal communication.

[28] *Ibid.*, "Late Tertiary Thrust Faults in the Mojave Desert, California," *Proc. Nat. Acad. Sci.*, Vol. XIV (1928), p. 11.

[29] W. H. Hobbs, "The Earthquake of 1872 in the Owens Valley, California," *Beitr. Geophysik*, Band 10 (1910), p. 379. Maps of Owens Valley faults by W. D. Johnson and C. F. Tolman were kindly loaned to the writers by Prof. C. F. Tolman, of Stanford University.

[30] J. C. Jones, "The Pleasant Valley, Nevada, Earthquake of October 2, 1915," *Bull. Seism. Soc. Amer.*, Vol. V (1915), pp. 190–205.

[31] James Gilluly, "Basin Range Faulting along the Oquirrh Range, Utah," *Bull. Geol. Soc. Amer.*, Vol. XXXIX (1928), p. 1116.

within it. It will be recalled, however, that the isoseismal lines of the earthquake are elongate along this line and may indicate a longer zone of movement than appears at the surface. It is evident that this belt should be considered in future structural studies in Nevada.

Recent faults in the Great Basin—that is, faults which traverse alluvial fans or separate them from the hard rock at the foot of the ranges—have been noted by many observers[32] and have been designated piedmont scarps by Gilbert[33] and fan scarps by Longwell.[34] Vertical movement only has been indicated or inferred for all recent scarps with the exception of at least one in the Owens Valley area and those in the area under discussion. It must be recognized that evidence of horizontal movement is probably obliterated for all those fan scarps that have been eroded unless it was sufficient to offset topographic features, and rarely is the movement of that magnitude. Furthermore, those fan scarps that antedate the advent of the white men were not crossed by roads or fences which serve as indicators of horizontal movement. Jones[35] found no horizontal offset of fences on the Pleasant Valley fan scarp formed in 1915. Hobbs[36] records offsets of as much as 20 feet in Owens Valley. The maximum offset observed at Cedar Mountain on any one rift was 34 inches.

Both the actual displacement and indicated movement on indi-

[32] I. C. Russell, "Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada," *U.S. Geol. Surv. Mono. XI* (1885), pp. 274–83; Gilbert, "Lake Bonneville," *U.S. Geol. Surv. Mono. I* (1890), pp. 340–62; Hobbs, *op. cit.*, pp. 352–85; A. C. Lawson, "The Recent Fault Scarps at Genoa, Nevada," *Bull. Seism. Soc. Amer.*, Vol. II (1912), 193–200; Jones, *op. cit.*, pp. 190–205; Knopf, "A Geologic Reconnaissance of the Inyo Range and the Eastern Slope of the Southern Sierra Nevada, California," *U.S. Geol. Surv. Prof. Paper 110* (1918), pp. 80–81; G. D. Louderback, "Basin Range Structure in the Great Basin," *Univ. Calif., Dept. Geol. Sci. Bull.*, Vol. XIV (1923), pp. 329–76; *ibid.*, "Period of Scarp Production in the Great Basin: California," *ibid.*, Vol. XV (1924), pp. 1–44; R. J. Russell, "Basin Range Structure and Stratigraphy of the Warner Range, Northeastern California," *ibid.*, Vol. XVII (1928), pp. 466–84; Gilluly, *op. cit.*, p. 1116; Gilbert, *op. cit.*, pp. 33–40; Longwell, "Faulted Fans West of the Sheep Range, Southern Nevada," *Amer. Jour. Sci.*, Vol. XX (1930), pp. 1–13; R. E. Fuller, "The Geomorphology and Volcanic Sequence of Steens Mountain in Southeastern Oregon," *Univ. Wash. Pub. in Geol.*, Vol. III (1931), p. 29.

[33] *Op. cit.*, p. 34.

[34] *Op. cit.*, p. 1.

[35] *Op. cit.*, p. 203.

[36] *Op. cit.*, pp. 379–80.

vidual rifts at Cedar Mountain show a southward movement of the east side relative to the west side. The pattern of the whole group of rifts within the rift area indicates a general southward movement of the eastern mountain block relative to the western. The relative horizontal movement in Owens Valley is the same.[37] These two examples of relative horizontal movement in the Great Basin correspond to horizontal movements on the San Andreas rift[38] along which the east side has moved south relative to the west side. It also correlates with the direction of overthrusting going on at the present time in an area a little to the east of the San Andreas rift.[39] Louderback[40] also states that the same relative movement has occurred on the Hayward rift. Eaton[41] reports the same relative movement on the Newport-Beverly shear zone on which the Long Beach earthquake is believed to have originated. Consideration of larger features of horizontal movement in western North America has been undertaken by Cloos.[42]

Certainly the relative horizontal movement within historical time is the same on two great structural lines, the San Andreas rift and the east front of the Sierra Nevada. It is also the same as that on what may be a third great structural line, as brought out in this study. As neither of the first two structures have been adequately

[37] *Ibid.*, p. 379.

[38] State Earthquake Investigation Commission, *op. cit.*, pp. 53–151; Bailey Willis and Robin Willis, *op. cit.*, p. 295; G. D. Louderback, "An Outline History of Earth Movements in the Central Coast Region of California in Late Pliocene and Post-Pliocene Time," *Proc. Fourth Pac. Sci. Congress*, Vol. II B (1930), pp. 846–47; J. E. Eaton, "Decline of Great Basin, Southwestern United States," *Bull. Amer. Assoc. Petr. Geol.* Vol. XVI (1932), pp. 24–25; L. F. Noble, "The San Andreas Rift in the Desert Region of Southeastern California," *Carnegie Inst. Year Book No. 31* (1932), p. 357; R. D. Reed, *Geology of California* (Tulsa: Amer. Assoc. Petr. Geol., 1933), pp. 11–12, 31–38.

[39] T. W. Koch, "Analysis and Effects of Current Movement on an Active Fault in Buena Vista Hills Oil Field, Kern County, California," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XVII (1933), pp. 694–712.

[40] *Op. cit.*, pp. 846–47.

[41] "Long Beach, California, Earthquake of March 10, 1933," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XVII (1933), No. 6, pp. 732–38.

[42] Hans Cloos, "Bau und Bewegung der Gebirge in Nordamerika, Skandinavien und Mitteleuropa," *Fortsch. d. Geol. u. Paleont.*, Band 7, Heft 21 (1928), pp. 281–94, 314–15, 317, 320.

explained, it is not possible to present a historical picture of the third for which there is so little information. The study indicates, however, that the underlying causes of movement in at least the western part of the Great Basin may be related to those in California, and that horizontal movements must be considered in future studies of Basin Range structure.[43]

[43] Acknowledgments.—The inhabitants of the region were uniformly helpful in supplying information concerning the earthquake. Captain H. S. Babbitt, U.S.N., Mr. L. B. Spencer, and Mr. Albert Brown were particularly helpful. Prof. Perry Byerly of the University of California, Dr. Harry O. Wood of the Carnegie Institution of Washington, and Messrs. N. H. Heck, Frank Neumann, H. E. McComb, R. R. Bodle, E. W. Eikelberg, and T. J. Mahar of the U.S. Coast & Geodetic Survey aided with suggestions and seismological data. The writers are indebted to Messrs. G. F. Loughlin, D. F. Hewett, and H. G. Ferguson, of the U.S. Geological Survey for critical reading of the manuscript.

THE LONG LAKE DIORITE AND ASSOCIATED ROCKS, SUDBURY DISTRICT, ONTARIO[1]

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Newton Highlands, Massachusetts

ABSTRACT

The igneous petrology of an area near the Long Lake gold mine, Sudbury district, Ontario, is described. The area lies at the contact of a region of folded sediments and one of granite-gneiss. Two rock types, Keweenawan diabase and Long Lake diorite, resulted from the injection of basic magma into the sediments. Later a large granitic batholith invaded the region. Reaction between the magma and the quartz-rich sediments is postulated to account for a border phase of very quartz-rich tonalite. The Long Lake diorite grades into a more acidic phase and this phase is explained as due to emanations from the batholith affecting the diorite and adding silica and soda.

INTRODUCTION

LOCATION

The area described lies between Lat. 46°15′ and 46°20′ and Long. 85°05′ and 85°15′, just north of the Panache area mapped by Quirke and Collins. It is only about 15 miles southwest of Sudbury in a direct line, but is quite difficult of access, owing to the rough nature of the topography. The area is near the southern border of the Canadian shield between a region of folded sediments and one of granite and gneiss.

STRATIGRAPHY

Collins[2] has noted that the rock formations in the area north of Lake Huron are grouped into four main structural elements:

> The four elements are, from oldest to youngest:
>
> 1. A pre-Huronian floor or basement upon which the other groups rest.
> 2. A thick succession of Huronian sedimentary formations and associated igneous formations lying in profound angular unconformity upon the pre-Huronian—or in the case of the intrusives—breaking through.

[1] Published with the permission of the Director of the Geological Survey of Canada. The writer wishes to acknowledge his indebtedness to Dr. T. T. Quirke, of the Geological Survey of Canada, and to Professors E. S. Bastin and A. Johannsen, of the University of Chicago.

[2] W. H. Collins, "North Shore of Lake Huron," *Can. Geol. Surv. Mem. 143* (1925), p. 15.

3. Palaeozoic formations, which rest in quite as profound angular unconformity upon the Huronian.
4. Unconsolidated Pleistocene glacial materials and lake beds, which lie unconformably upon all the older groups.

In the area under consideration only elements 2 and 4 are found, and of these two, the latter has no special significance for the purposes of this report.

The pre-Cambrian rocks may be arranged as in the accompanying list, with the youngest at the top.

4. Scattered dikes of fresh olivine diabase, apparently much younger than any of the other pre-Cambrian formations.
3. Killarnean batholithic intrusions.
2. Sills and dikes of diabase, quartz-diabase, diorite, and tonalite, probably of Keweenawan age.

IGNEOUS CONTACT

1. Bruce series, consisting of
   - *a*) Serpent quartzite
   - *b*) Espanola formation
   - *c*) Bruce conglomerate
   - *d*) Mississagi formation

BRUCE SERIES

All of the sediments of the region belong to the Bruce series, Lower Huronian in age, and the other three groups of rocks are igneous and intrusive into the sedimentary formations. All members of the Bruce series are represented, but no other Huronian formations have been spared by erosion.

The Bruce series is, however, so metamorphosed that its original sedimentary character is largely masked. *Memoirs 102*, *143*, and *160* of the Geological Survey of Canada contain excellent descriptions of these rocks from the typical areas, and describe the metamorphic changes produced in them. The sediments are predominantly impure feldspathic quartzites and graywackes.

KEWEENAWAN DIABASE

The diabasic rocks, intruding the Huronian and pre-Huronian formations as dikes and sills, have been described in many reports

and papers. The most complete accounts appear in memoirs of the Geological Survey of Canada, of which five are listed below.[3] Rock of this type is widespread in the region north of Lake Huron, occurring as far north as the Cobalt and Gowganda areas, and is perhaps correlative with the Keweenawan intrusives of the Lake Superior region.

The diabase is typically a massive, quite fresh-appearing, dark-greenish-gray to black rock, with size of grain varying with the thickness of the intrusive mass. Small dikes are dense, black, and basalt-like, and at the other extreme thick sills are gabbro-like (6 mm. minerals), although the usual grain in most sills is medium (about 2 mm.). Within the sills the diabase also varies in appearance and mineralogical composition, owing to assimilative and differentiative processes in the more slowly cooling magma. There are patches of much coarser material, a yard or so across, that rarely show definite boundaries against the more usual phases. Infrequent dikes of a red-to-white aplitic differentiate cut the diabase, and "red rock" occurs in indefinite patches of dull-reddish material, which owes its color to the fact that the feldspar is red instead of light gray in reflected light.

Fine-grained fresh phases have a diabasic texture and are composed of intermediate labradorite and augite in about equal proportions, with a little quartz in the angular interstices between the chief minerals and with accessory titaniferous magnetite and apatite, and a very little biotite, pyrite, and chalcopyrite. The pyroxene is very often altered to green hornblende.

The coarser phases show more mineralogic variability. The plagioclase is more variable, ranging from bytownite in some places to andesine in others. A micrographic intergrowth of quartz and andesine is present in amounts over 10 per cent in some places. The most acidic plagioclase outside the intergrowth is optically identical with that in the micrographic intergrowth. When some titanite and biotite are present in coarse diabase, the plagioclase is usually red in re-

[3] *Mem. 33* (1913), pp. 59–63 and Pl. III, Figs. 3, 4, and 15; *Mem. 95* (1917), pp. 84–101 and Pl. VII B, VIII A and B, X A and B; *Mem. 102* (1917), pp. 49–55; *Mem. 143* (1925), pp. 77–82 and Pl. XIV A and B; *Mem. 160* (1930), pp. 29–30, 37, and 99–101. The most extended discussion is given in *Mem. 33*, and the discussions in the later memoirs are, in large part, summaries of the original one.

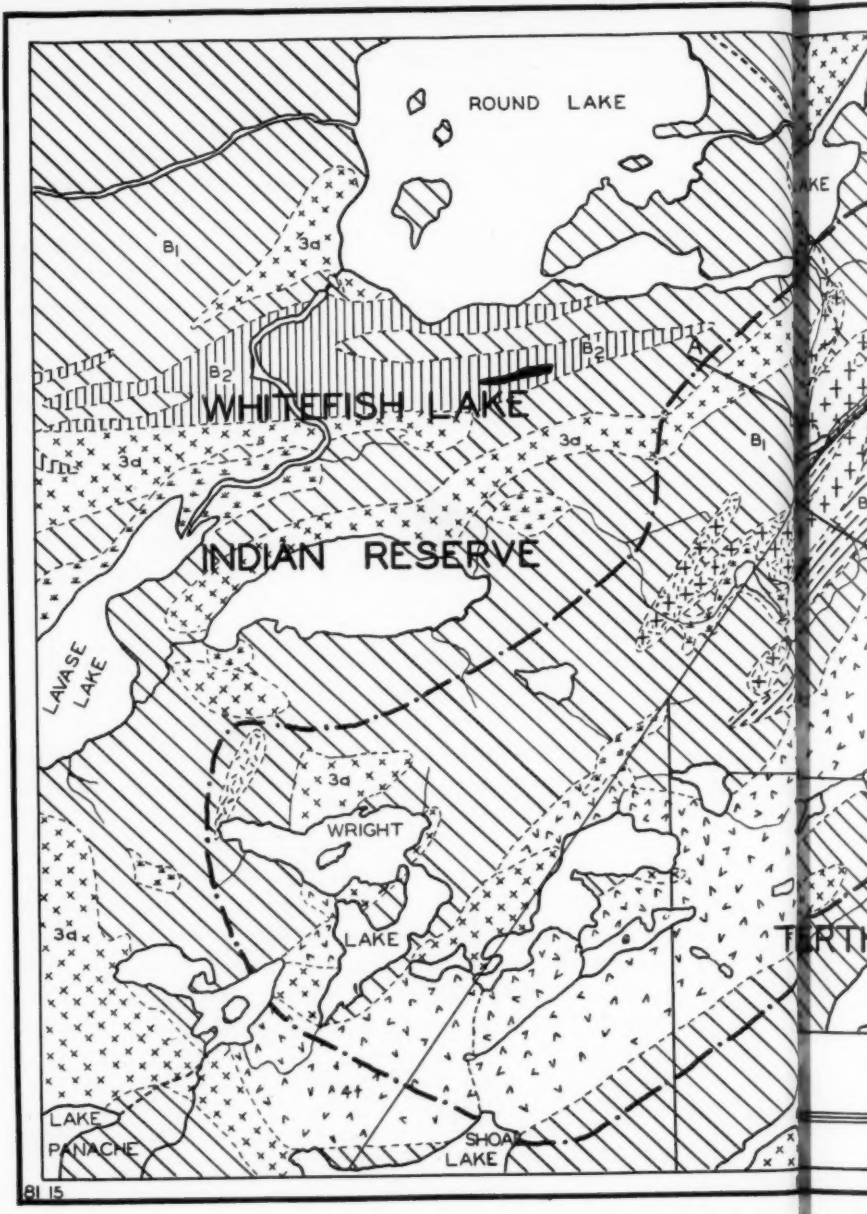
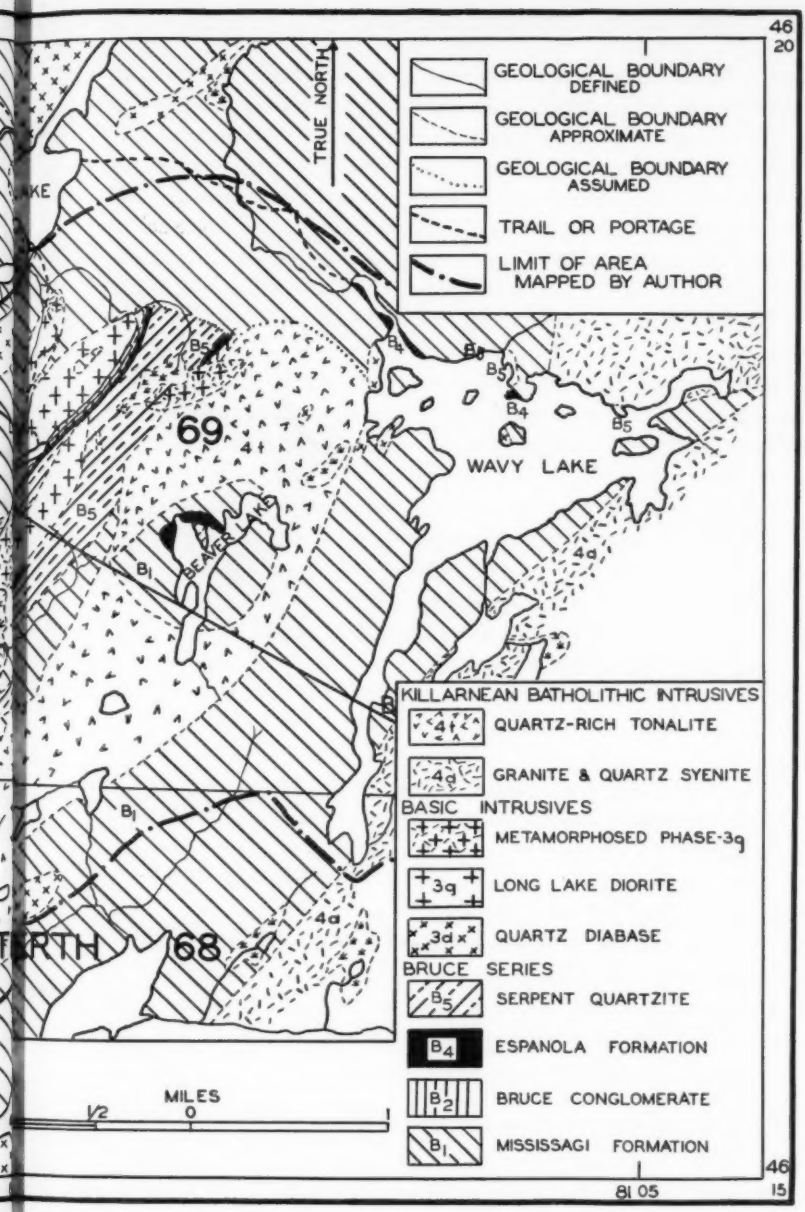


FIG. 1.—Geological map Long L



Long Lake Gold mine

flected light. This phase, composed of acidic plagioclase, biotite, micrographic intergrowth, and titanite, with some magnetite, is called "red rock" when it occurs in fairly large masses; however, it does occur in all proportions mixed with diabase, varying from numerous small red spots up to sizable masses that contain little diabase. Aplite differs from "red rock" in that it has a much more acidic plagioclase, some of which is practically pure albite, and it contains no magnetite. The texture of both "red rock" and aplite is granitic.

Collins interprets the association of the three above-described rock types, namely, coarse diabase, "red rock," and aplite, as due to crystallization differentiation in the magma, although he does not exclude the possibility that assimilation of sediments has affected the course of differentiation. He has shown that some assimilation has taken place.[4]

Metamorphic effects of the diabase.—Where the diabase has invaded the older formations without breaking off and engulfing fragments its metamorphic effects are not very marked. Huronian quartzite was rendered glassy and more perfectly recrystallized for a short distance from the contacts, varying from a few inches to several feet. Graywacke is bleached for a distance of about 1 yard from the diabase, is filled with black spots of chlorite, and becomes essentially a recrystallized aggregate of quartz and acidic plagioclase.

In all sizable masses of diabase there are occasional lighter patches very much coarser grained than the surrounding rock. In some of these there is a core of corroded quartzite. The boundaries are usually indefinite. The distribution is variable, but in places the patches amount to 10 per cent of the total. Collins has shown that these lighter patches represent inclusions partly assimilated by the diabase magma.[5] It is quite possible that the assimilation of such a large amount of sedimentary material had an appreciable effect on the course of differentiation of the magma.

[4] "The Geology of the Gowganda Mining Division," *Can. Geol. Surv. Mem. 33* (1913), p. 80.

[5] "Onaping Map-Area," *Can. Geol. Surv. Mem. 95* (1917), pp. 61–62.

OLIVINE DIABASE

Olivine diabase is very widespread in the region, always occurring as dikes, most of them small, but some fully 100 feet wide. Only a few occur in this area, and they are so small that they are not shown on the accompanying map. M. B. Baker, however, has shown four on his map of the vicinity of the Long Lake gold mine.[6] Olivine diabase is the youngest rock in the region, if the Pleistocene deposits are excepted, and cuts all the other rocks. It is separated from the quartz diabase by the episode of the intrusion of the Killarney granite.[7]

Megascopically the rock resembles quartz diabase, and can be separated from it in the field only with difficulty. Olivine diabase, however, appears fresher, with brighter, more glassy feldspar. It is a fresh, black rock consisting of labradorite, olivine, and magnetite

FIG. 1a.—Structure section along line *A–B* on map

crystals in a base of purplish-brown, titaniferous augite. The rock consists of approximately 60 per cent zoned labradorite, 30 per cent augite, 10 per cent olivine, and accessory magnetite, biotite, and apatite. The texture is intergranular, a variety of ophitic texture in which the interstitial augite is in grains and not in large crystals.

THE LONG LAKE DIORITE

CHARACTER OF INTRUSION

The intrusive mass of the Long Lake diorite outcrops in an irregular form. There are five masses: a larger, irregular central mass with four smaller lenticular masses around it. Since the total length is 3 miles, and the greatest width $\frac{3}{4}$ mile, it is, therefore, about four times longer than it is wide. It appears to conform generally to the

[6] "Long Lake Gold Mine, Sudbury District," *Ont. Bur. Mines, Ann. Rept.*, Vol. XXVI (1917), Map 26*e*.

[7] Collins, "North Shore of Lake Huron," *Can. Geol. Surv. Mem. 143*, p. 84.

strikes and dips of the adjacent sedimentary formations, although the contacts are transgressive to a limited degree in some places. The rocks of the Bruce series are nearly vertical, forming a closely appressed syncline. The diorite intrusive is mainly in the northwest limb of the syncline, with the exception of the mass 1 mile north of Beaver Lake which is in the other limb. Apparently the injection followed the folding of the sediments and the diorite pushed the rocks aside to make room for itself.

Brecciated contacts are widespread, but are particularly well shown near the mine road about $\frac{1}{4}$ mile south of Long Lake. Here the Mississagi quartzite is brecciated and tongues of diorite fill in around the angular blocks. Elongated, altered quartzite inclusions occur well within the diorite.

The diorite outcrops in ridges resembling a series of parallel dikes, since erosion has been more rapid along certain planes of weakness. These dikelike outcrops have practically vertical walls, 5–20 feet high, and variable widths extending about 300 feet. The shores of Luke Lake, which lies almost in the center of the diorite mass, furnish excellent outcrops.

TYPICAL PHASE

The usual rock type, and the one considered typical, is megascopically a fine- to medium-grained, dark-gray rock composed mainly of feldspar and hornblende in about equal amounts. It closely resembles a diabase, and many outcrops were called diabase in the field because of this resemblance.

The texture is hypautomorphic-granular and subophitic, with a slight tendency to parallelism of the hornblende and feldspar individuals. Both minerals are lathlike in habit, as is particularly well shown in some hornblende individuals which have a length as much as 7 mm. in specimens otherwise only millimeter grained (Fig. 2.)

Plagioclase and hornblende, with plagioclase only slightly in excess, make up nearly all the rock. A very small amount of quartz is present as well as 1 or 2 per cent of biotite. Titaniferous magnetite and apatite are constant accessories. As secondary minerals clinozoisite is always present and flakes of white mica are commonly found as alteration products of plagioclase; a little chlorite is ordinarily secondary after hornblende.

The plagioclase in the fine-grained rock type is andesine-labradorite. In one case zoned crystals were found with centers as basic as $Ab_{30}An_{70}$, but this is unusual. The composition varies from $Ab_{30}An_{70}$ to $Ab_{60}An_{40}$, but the usual composition is between $Ab_{55}An_{45}$ and $Ab_{50}An_{50}$.

The more basic centers of the plagioclases are generally somewhat altered. Clinozoisite is developed in them to a notable extent and there are flakes of white mica. In only a few cases, however, is the entire crystal altered to a saussuritic mat of interlocking fibers.

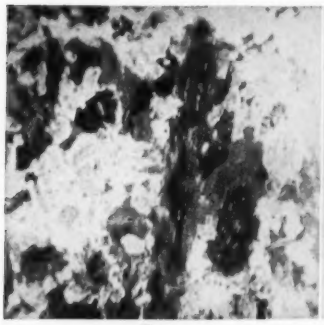


FIG. 2

FIG. 3

FIG. 2.—Typical Long Lake diorite. Ordinary light. ×10. The dark mineral is hornblende.

FIG. 3.—Secondary garnet in poikilitic hornblende with quartz chadacrysts. Ordinary light. ×30.

Often the center of the crystal is unaltered, but an intermediate zone is altered. The rim in almost all cases is remarkably clear and fresh appearing, and is often untwinned. The plagioclase is in crystals about twice as long as wide, but there is practically a complete absence of automorphic boundaries. It is quite fresh, but albite twinning usually is not well developed.

The amphibole is the blue-green variety of common hornblende ordinarily found as a primary mineral in igneous rocks. The individuals are in lath-shaped crystals; none of them has the terminal faces developed and most of them are ragged and indented along the sides (Fig. 2). When basal sections are shown, however, a good

many crystal faces can be seen with the characteristic angles. If this mineral were secondary after pyroxene such outlines would not be present unless the whole rock has been recrystallized, and there is no evidence that this has occurred. In practically all cases hornblende laths dominate the texture, both microscopically and megascopically. In most hornblende crystals there are black specks and dots of magnetite which are arranged in a roughly linear fashion and are more numerous in the centers of the crystals than near the edges. The larger crystals are cracked by minute cross-fractures. There are a few flakes of biotite within most crystals, and often a small amount in parallel intergrowth with the hornblende. Some alteration to chlorite is shown, but on the whole the hornblende is notably fresh. In a few cases pleochroic halos occur.

VARIATIONS

The diorite varies in appearance, owing to the local presence of rock types caused by differentiation in the cooling magma, possibly by assimilation, and by metamorphism by the later Killarney batholith. Five such variations are described.

1. *Coarse-grained patches.*—Coarse segregations are apparently due to slow crystallization. Two sets of specimens were taken across gradations from fine- to coarse-grained material. With increasing coarseness there was an increase in the amount of primary quartz and the hornblende crystals became more irregular in outline. These changes would be expected in the more slowly solidifying parts of a magma. Any excess of free silica would collect in the places where solidification was slowest and would crystallize last. The raggedness of the hornblende crystals is probably the result of reaction with the remaining magma, and the slower the crystallization the more time was available for reaction between the already crystallized hornblende and the liquid residue.

2. *Reddish dikes.*—At the small island in Luke Lake there is an outcrop of a red rock, and 300 feet west of the outlet on the north shore there are ramifying stringers of the same material, 4–14 inches wide, with sharply defined but irregular contacts, cutting the diorite. This rock type is a dull-reddish-gray, medium-grained (2 mm.), granular-textured rock that does not resemble any other rock in the

area, but agrees quite well with published descriptions of the "red rock" associated with the Keweenawan diabase.[8] The rock at Luke Lake is composed of 82 per cent reddish-colored oligoclase ($Ab_{75}An_{25}$) 5 per cent quartz, 10 per cent biotite, with hornblende, apatite, titaniferous magnetite, and pyrite making up the remaining 3 per cent. Bowen thought that the red rock of the Gowganda area resulted from interaction at the contact, some of the sediments being assimilated by diabase magma to give a mixture that solidified with the textures of an igneous rock.[9] Collins, however, concluded that red rock is a normal differentiate of the diabase magma that has not been affected by assimilation.[10] Whatever the origin, the presence of this rock type suggests a relationship between the Long Lake diorite magma and the Keweenawan diabase magma.

3. *Metamorphosed phase.*—The metamorphosed phase is confined mainly to the peripheral parts of the intrusive. In the field the only constant accompaniment of alteration is the Killarney intrusives. One mass, $\frac{3}{4}$ mile north of Beaver Lake, lies partly within the large mass of Killarney tonalite stretching from Wavy Lake to Wright Lake. All of the rocks, diorite and Bruce sediments, northeast of Luke Lake are fairly riddled by small outcrops of very quartz-rich Killarney intrusives. These small quartz-rich tonalite masses, many of which are dikelike, would seem to indicate a very close approach of the Killarney batholith to the present surface. This close association of Killarney tonalite and altered diorite suggests a genetic connection, and the writer believes that the tonalite caused the metamorphism.

Within very short distances the metamorphosed rock varies notably in color, in texture, and in mineralogy. These variations range from little-altered diorite to a medium-grained rock, light gray, granular in texture, composed of plagioclase, biotite, and quartz, and resembling a dark-colored granite or a syenite in the field.

The constituents, as determined under the microscope, with their

[8] Collins, *op. cit., Mem. 33,* p. 63, and *op. cit., Mem. 95,* pp. 92–94; N. L. Bowen, "Diabase and Granophyre of the Gowganda Lake District, Ontario," *Jour. Geol.*, Vol. XVIII (1910), pp. 658–74.

[9] *Ibid.*, p. 673.

[10] *Ibid.*, pp. 92–94.

approximate percentages are: oligoclase between $Ab_{70}An_{30}$ and $Ab_{80}An_{20}$, about 70 per cent; quartz, 10 per cent; biotite, 15 per cent; hornblende, 1 or 2 per cent; with garnet, titaniferous magnetite, and apatite as accessories. The main changes involved are: reduction in the amount of mafic constituents, especially hornblende; a marked increase in the sodic character of the plagioclase; the introduction of a notable amount of quartz; the presence of accessory garnet; and reduction in amount of titaniferous magnetite.

The garnet resembles grossularite and is probably an iron garnet. It is associated with the mafic constituents more closely than with others. There is a suggestion that it may have pushed the hornblende aside in crystallizing (Fig. 3), and this, if true, means that it is present as metacrysts. Some of the biotite is developed as metacrysts and has replaced the original rock to make room for itself.

Quartz occurs as both a primary and a secondary constituent. Part of it is in small crystals among the other constituents as is the normal habit of primary quartz, but the larger part is present as small, rounded chadacrysts in the hornblende, which is very markedly poikilitic (Fig. 3). In extreme cases the hornblende, and, at times, biotite also, is shredded by introduced quartz to such an extent that only small remnants remain in large quartz aggregates. A small amount of quartz is also present as small irregular stringers in feldspar.

The foregoing indicates that the changes produced in the diorite as it was metamorphosed were: (1) the introduction of quartz into the rock, principally into the hornblende as chadacrysts, producing a marked poikilitic habit in the hornblende; (2) the introduction of soda, causing the plagioclase to become more acidic (andesine-labradorite became oligoclase); (3) the reduction in amount of the dark constituents, owing to the combined influence of the silica and soda; (4) the reorganization of hornblende into biotite; (5) the formation of garnet—probably owing to the influence of the iron in the magnetite.

Any one of three possible processes, or combinations of them, might account for these changes:

a) Crystallization differentiation.—The changes described could be produced by the settling of more basic crystals in the liquid magma during the course of normal crystallization differentiation.

b) Assimilation of sedimentary rocks.—The Huronian quartzite might react with the magma so as to add the soda and quartz.

Both of these processes would be operative while the magma was still liquid.

c) Metamorphism by emanations from the quartz-rich tonalite.—The altered rock is in very close association with outcrops of tonalite, as noted on page 33. The appearance of this rock type differs from that of material known to have been assimilated, as described on the following page. The presence of rounded blebs of introduced quartz in the mafic constituents is very strong evidence that the changes occurred after solidification of the magma, and metamorphism by emanations is the only one of the three processes that would be operative in the solid state. For these reasons the writer believes that the rock type under consideration is an altered phase of the diorite, metamorphosed by the tonalite.

4. *Patches.*—Patches characterized by extremely long and thin hornblende laths and associated with the metamorphosed phase show a decided orientation of the minerals. The hornblende and biotite are extended in a plane roughly parallel to the present surface. These minerals have a remarkable development in this plane and cause the outcrops to scale off in large thin layers, a yard or so across and only an inch or two thick. This layered character could have been brought about only by crystallization under directed pressure, and therefore in a state approaching the solid, i.e., by piezo-crystallization. The writer concludes that the formation of the hornblende and biotite in these variants took place under a directed pressure caused by the presence of the Killarney batholith a short distance below. The patches, therefore, are also considered a metamorphosed phase of the Long Lake diorite and were caused by the intrusion of the Killarney batholith.

5. *Metamorphism and assimilation by the diorite.*—There are numerous xenoliths within the intrusive, four of which are large enough to be shown on the map. These inclusions are altered and recrystallized to a large extent and the smaller ones are completely changed. One example, $\frac{1}{8}$ mile west of the head of Luke Lake and 100 feet south of the large xenolith of Mississagi formation, is an altered patch 10 by 4 feet with a fairly definite boundary against the diorite.

Within this patch hornblende, plagioclase, and quartz are in a confused intergrowth. Quartz weathers out into little masses like runic characters, and the hornblende metacrysts are an inch or more in length. Thin sections of this rock show that the minerals have interlocking boundaries.

In another place, a quarter of a mile south of the one just described, a somewhat larger mass of quite light-colored, feldspar-rich material lies within diorite. The light material is not homogeneous, but has variegated bands of much darker material which are rich in hornblende. Hornblende is present as metacrysts lying in a base of subparallel, andesine laths and quartz crystals and enclosing some of these minerals. Collins has described similar cases in the Keweenawan diabase from the Gowganda area,[11] and from the north shore of Lake Huron.[12]

The most striking product of metamorphism, however, is a spotted rock composed of white feldspar with irregular, rounded, hornblende metacrysts about 1 cm. in size. The hornblende weathers into relief to produce a rough surface. In thin section the rock is seen to be composed mainly of hornblende and labradorite in proportions about 1 to 2, although the proportions vary noticeably. The feldspar crystals wind about and lie within the hornblende metacrysts.

COMPARISON OF DIORITE AND DIABASE

On comparing the Keweenawan diabase and the Long Lake diorite, certain strong similarities between them are evident: (1) in age both belong to the time between the deposition of the Huronian sedimentary formations and the intrusion of the Killarney granite; (2) both contain "red rock" although the amount in the diorite is relatively small; (3) both contain coarse segregations; (4) the chemical composition of the diorite, as computed from Rosiwal's analyses, agrees closely with published analyses of the diabase; (5) the two rock types are very similar in hand specimens, and therefore are distinguishable in the field only with extreme difficulty.

On the other hand, differences exist which are great enough to cause Collins to regard them as separate intrusions:[13] (1) the chief

[11] *Can. Geol. Surv. Mem. 95*, pp. 61–62.

[12] *Ibid., Mem. 143*, p. 80.

[13] Personal communication, April 1, 1932.

mafic constituent is primary hornblende in the diorite and pyroxene (which is largely amphibolized) in the diabase; (2) the plagioclase is somewhat more sodic in the diorite; (3) quartz is smaller in amount in the diorite, (4) micrographic intergrowth is absent in the diorite; (5) the diorite grades into a tonalitic phase, which the writer regards as a metamorphosed phase of the diorite.

The writer believes that the magmas of the diorite and diabase came from a common source and that the differences are due (1) to a different course of differentiation, and (2) to the effect of the Killarney batholithic intrusives on the diorite, as will be considered more fully later in the report.

KILLARNEY BATHOLITHIC INTRUSIVES

DISTRIBUTION

Killarney batholithic intrusives are widespread in the area and are much more pervasive than the diorite and diabase. The granite shown at the eastern side of the area is part of a large mass that extends with some interruptions to Killarney on Georgian Bay.[14] A mass of very quartz-rich tonalite extends from Wavy Lake to Wright Lake. These two rock types are shown on the accompanying map, but an enormous number of pale-gray, quartz-rich tonalite dikes, similar in appearance and mineralogical composition to the large mass, cut all the other formations without regard to their structure and are too small to be shown on a map of this scale.

QUARTZ-RICH TONALITE

The tonalite is a pale-gray, medium-grained (3–4 mm.), equigranular rock composed mainly of quartz and oligoclase ($Ab_{85}An_{15}$) in about equal proportions, with a little potash feldspar, mainly microcline, a few per cent of biotite, and accessory titaniferous magnetite, and apatite.

Numerous dikes and small masses of similar rock surrounding the quartz-rich tonalite mass make the location of the contact with the sediments a matter of individual judgment. East of Wright Lake the Mississagi formation is severely metamorphosed and intruded by a host of small offshoots from the batholith. The diabase mass north of Wright Lake is also cut by numerous dikes and is altered to rock in

[14] *Op. cit.*, *Mem. 160*, Map 220A, Panache Sheet.

which the hornblende laths are prominent and which resembles very strongly the Long Lake diorite. As mentioned on page 33, there is also a very large number of small intrusive masses northeast of Luke Lake.

The dikes are irregular in shape. Some are wall shaped, others resemble lenses, or are irregularly shaped. The quartz grains are especially resistant to weathering and protrude about $\frac{1}{8}$ inch above the other constituents, thus forming a rough surface. These grains when crushed under foot make a peculiar crunching, grinding noise. This peculiarity of weathering makes it easy to distinguish in the field between quartz-rich and quartz-poor dikes, both of which are present. These dikes are fresh, unsheared, not displaced, and apparently are the last manifestations of the batholithic intrusion. Their contact effects on the sediments seem to be almost nil. They show no chilling or difference of grain within themselves. Even little dikes, 6 inches wide, are medium grained from edge to edge.

The chief difference between the dikes and the large masses of tonalite is the different nature of the contacts. Almost everywhere large masses pass into quartzite by a complete gradation. On a traverse from the southwest end of Luke Lake southeast to the small lake on the boundary between timber berths 68 and 69, patches of gray, quartz-rich, igneous-appearing rock were found in the Mississagi quartzite $\frac{3}{4}$ mile from Luke Lake, about where the small stream enters the swamp. Farther along the traverse these patches became more and more numerous and larger, until at a distance of 1 mile from Luke Lake the igneous rock was in excess and sediments were contained in it. The outcrops were very numerous and sharp contacts especially were searched between bedded and cross-bedded feldspathic quartzite and the gray tonalite. Practically none was found; the bedding planes in the pinkish-gray quartzite faded out next the intrusive and the rock appeared gray, somewhat coarser grained, and with fresher minerals. The feldspar especially was gray, with bright cleavage faces 2 or 3 mm. across, whereas in the sedimentary rock it was dull reddish, without noticeable cleavage faces.

The conclusion seems unescapable that the large masses of tonalite either originated in place or else assimilated enough of the country rock after emplacement to produce the gradational contacts.

GRANITE

The granite is a coarse, reddish rock composed largely of phenocrysts of orthoclase, with 5–10 per cent quartz, some oligoclase-albite, and a little biotite.

On the north shore of Wavy Lake, at the contact between Huronian quartzite and granite, the quartzite is very much metamorphosed, highly sheared in a vertical plane, and altered into a complex of highly schistose muscovite rock and vitreous translucent quartz. The phenocrysts of the granite are alined and also sheared internally, but the base is not noticeably affected. The granite appears to have been pushed into place, shearing internally, and shearing against the quartzite when it was essentially solid. Numerous quartzite xenoliths are within the granite and these appear to be in parallel orientation with the sediments outside. No twisting or rotation of the xenoliths occurred, in spite of the shearing of them and of the granite, probably because the granite came up vertically and merely tore off slivers of quartzite which it carried up bodily with it.

The line of contact between the main Killarney batholith and the sediments was drawn near the east side of Wavy Lake. West of this line the rocks are prevailingly sediments cut by small, gray, granite dikes. East of this line the rocks are dominantly coarse, pink granite with minor but clearly sedimentary inclusions many of which are more or less completely granitized. This contact is a most important line of division and probably marks the position of a great dislocation. Presumably the area east of the contact was once covered by an upper tonalite differentiate and this in turn by Huronian sediments, and the area west of the line of contact is, by the same reasoning, underlain at depth by granite.

AGE RELATIONS OF THE IGNEOUS ROCKS

GRANITE

The pink granite is so typically Killarnean in aspect that there can be no doubt of its identity with the Killarney granite.

TONALITE AND GRANITE

Gray tonalite dikes are very numerous at the contact of granite and sediments. The prevalence of gradational contacts between the larger masses of tonalite and sediments has been noted above. The

composition of the sedimentary series is quite similar to a very quartz-rich, soda granite. Reaction between the magma of the Killarney granite and inclusions of the type of the impure quartzites of this area would produce a reaction product similar to the quartz-rich tonalite.[15] The writer believes that the field relations are best explained by reaction between the granite magma and the sediments. The larger masses of tonalite originated, according to this view, approximately in the place that they now occupy, and the smaller dike-like masses were squeezed out of the larger masses during their solidification. The sediments had been sufficiently heated since the intrusion of the Long Lake diorite so that reaction between granite magma and sediments could take place and small dikes of tonalite could solidify without chilling. That the great batholiths of the Canadian shield had an enormous effect on the overlying rock has long been recognized. In 1921 J. Barrell said that it was probable that pervasive magmatic waters emanating from granite magmas had caused the regional alterations of the Keewatin lavas.[16] The work of Quirke and Collins in the Area immediately south of this one also supports the contention of large-scale alteration by the processes of batholithic invasion. Indeed, they claim a very large amount of formation of igneous rock in place. They say:

> In places where liquid masses were intruded from greater depths towards the upper part of the crust replacement was negligible, and sharp contacts . . . . resulted. But at great depths . . . . igneous intrusion was either antedated or usurped by enormous metasomatism, whereby the rocks were so profoundly altered, through soaking with magmatic emanations, that their composition and textures were notably altered.[17]

The writer believes that the tonalite originated under some such conditions and that it was emplaced quietly through processes of regional metasomatism and assimilation of the overlying sediments. The description of the changes in the Long Lake diorite to produce the metamorphosed phase is another record of the workings of these processes. The lack of definite contacts between the larger quartz-rich tonalite masses and the Huronian quartzites is also evidence of

[15] Bowen, *op. cit.*

[16] "Relations of Subjacent Igneous Invasion to Regional Metamorphism," *Amer. Jour. Sci.*, Vol. CCI (1921), p. 180.

[17] *Can. Geol. Surv. Mem. 160*, p. 95.

the quiet invasion of country rock at considerable depth by an igneous rock. This quiet invasion is also evidenced by the shape and position of the metamorphosed mass of diorite lying partly within quartz-rich tonalite. Had the intrusion been violent there should be evidence of crosscutting by the igneous rock, so common in rocks intruded at slight depths.

TONALITE AND DIORITE

The Long Lake diorite has been assigned to the same period as the granite by most previous investigators,[18] who appeared to consider it a basic marginal phase of the granite. Baker, however, states that it is cut by granite and is therefore somewhat earlier. A negative reason for not believing that the diorite and granite are intimately related in origin is the absence of basic borders about the granite elsewhere in the general district. The batholiths of Killarney age in the district are believed by Quirke and Collins to have originated about 6 miles below the surface, but even at that depth they find no trace of the source of any basic magma.[19] If the other Killarney batholiths are not the result of differentiation from a basic magma, no reason exists to believe that this one is.

The writer found numerous localities where the diorite was cut by tonalite dikes. The mass of metamorphosed diorite lying partly within the tonalite northeast of Luke Lake is cut by numerous tonalite dikes and irregular offshoots. A very significant outcrop is found 200 feet south of the east end of this mass. Here Serpent quartzite is cut by two dikes, one of coarse tonalite, the other of fine diabasic appearing diorite, apparently coming from the large mass to the north. The tonalite is about 25 feet long, 2 feet wide at the east end, irregular in width, pinching and swelling, ending in a club-shaped widening at the west end, but about 3 feet wide on the average. It is coarse grained from edge to edge and shows absolutely no chilling at the borders. The diorite dike is 4 feet south of the tonalite dike and about parallel with it. It is 15 feet wide, is exposed for 35 feet, and appears to be coming from the large dioritic mass. It is fine grained

[18] A. P. Coleman, "The Pre-Cambrian Rocks North of Lake Huron," *Ont. Bur. Mines Ann. Rept.*, Vol. XXII (1914), p. 219; M. B. Baker, *ibid.*, Vol. XXVI, Part I (1917); W. H. Collins, *Can. Geol. Surv. Mem. 143*, p. 121.

[19] *Op. cit.*, *Mem. 160*, p. 98.

from edge to edge. The two dikes are not in contact so that their relative age is not absolutely definite. Neither is sheared. In thin section the small tonalite dike resembles sections from large masses of the same rock. Since the dioritic dike has andesine feldspar, 10 per cent quartz, no hornblende, and 20 per cent biotite, as well as 2 per cent garnet, it is, therefore, the metamorphosed phase of the diorite.

The diorite must have preceded the tonalite by a period sufficient to allow the solidification of the dike in relatively cool country rock. The tonalite must have been intruded into heated rocks, or such a small mass as the one under consideration would have been chilled. After the intrusion of the diorite and the solidification of dikes from the main mass the sediments into which it had been injected were heated by the underlying Killarney batholith so that the small tonalite intrusions were not notably warmer than the rocks into which they were injected. The Long Lake diorite is thus older than the quartz-rich tonalite by an appreciable amount.

DIABASE AND GRANITE

The Keweenawan diabase is also older than the Killarney intrusives. The writer believes that both basic rock types belong to the same period of intrusion—a period somewhat earlier than that of the Killarney granite—and that the differences between diorite and diabase are largely due to metamorphism of the diorite intrusion by emanations from the Killarney batholith.

Both diorite and diabase are younger than Bruce sediments and older than the Killarney granite. This interval is an extensive period of time, however, and there may have been two periods of basic intrusion. The relation of the Sudbury norite to the granite may throw some light on the age relationships here. Collins has noted[20] that the Keweenawan diabase is widely distributed in the region between Lake Superior and the Ontario-Quebec boundary. He showed further that these rocks in the Cobalt and Gowganda areas[21] varied regionally from a type of gabbroic composition at the north to one of noritic composition at the south, and therefore correlated the Sudbury norite lopolith with the diabase sills. He shows four masses of Killarney granite in contact with the south edge of the norite on

[20] *Ibid.*, p. 29.

[21] *Op. cit.*, *Mem. 143*, p. 80.

his large map of the district.[22] The relative ages of the granite and norite has been a controversial question ever since they have been studied. Granite intrudes norite at the Murray mine. Three miles southeast, at Copper Cliff, the norite has cooled against granite at No. 2 mine. A mile north, at Clarabelle Lake, granite intrudes the norite, as occurs also near the Creighton mine. The writer verified these facts in 1929 although they had been noted in the literature much earlier.[23]

DIABASE AND DIORITE

Such a train of reasoning places the Keweenawan diabase very close in age to the Killarney batholithic intrusion, and it is possible that the intrusion of basic rocks marked the opening stage of igneous action in the region. If this is the case, then it would be quite probable that smaller masses, such as sills and their feeding dikes, would solidify much more rapidly than such a large mass as the Sudbury lopolith. The Long Lake diorite would also solidify more slowly than the sills, not only because of its greater mass, but also because the heat generated by the crushing and brecciation of the sediments during its emplacement would tend to prolong the period of crystallization. This longer period of crystallization would also allow more time for differentiation and assimilation, and it is quite possible that this accounts for the presence of primary hornblende instead of the pyroxene usual in the sills.

The Keweenawan diabase sills, east of Lake Panache and immediately south of this area, are metamorphosed by the Killarney granite to a type resembling the dioritic types common in other regions around the edges of batholiths.[24] The diabase on the north shore of Wright Lake is also altered to a type that megascopically resembles very closely the Long Lake diorite.

The writer believes, therefore, that the Long Lake diorite magma came from the same source as the diabase and that it differs from it in character because of a more protracted period of solidification during which assimilation and crystallization differentiation and

[22] *Can. Geol. Surv.* (1929), Map 155A, Lake Huron Sheet, scale: 1 in. = 8 mi.

[23] A. E. Barlow, "The Nickel and Copper Deposits of the Sudbury Mining District," *Can. Geol. Surv. Ann. Rept.*, Vol. XIV, Part H (1901), p. 53.

[24] Quirke and Collins, *Op. cit.*, *Mem. 160*, p. 30.

especially emanations from a rising Killarney batholith were operative. The effects of assimilation and differentiation were more severe on the diorite than on the diabase probably because of its longer period of cooling and consequent higher temperatures. What is called the metamorphosed phase of the diorite owes its character to still further modification by emanations from the granite batholith. It should be added, however, that there is no absolute proof that the diorite was not a later intrusion than the diabase sills and dikes.

OLIVINE DIABASE

Olivine diabase dikes cut the Killarney granite at points outside the area and are, therefore, the youngest intrusive rocks in the region. They are usually assigned to a late Keweenawan age.

SEQUENCE OF INTRUSION

The writer's conception of the sequence of intrusion is as follows:

Basic magma was injected into the sediments of the Bruce series as they were being folded. Most of the sills and dikes did not undergo any very pronounced differentiation and solidified as Keweenawan diabase, but one mass differentiated to a somewhat greater degree and solidified as the Long Lake diorite.

A little later a large granitic batholith invaded the region and during its period of solidification the magma reacted extensively with the quartzite sediments, producing a border phase of quartz-rich tonalite. Emanations from the batholith also affected the Long Lake diorite, adding silica and soda to the rock, with the result that the diorite now grades into a more acidic phase, here called the "metamorphosed phase."

The writer agrees with Quirke and Collins who say that the source of the basic magma is not known, but is thought to have been different from that of the granitic magma, which was very probably derived from the melting of very deeply buried sediments of the Bruce series.[25]

Dikes of olivine diabase were injected after the complete solidification of all of the other rocks.

[25] *Ibid.*, p. 98.

THE NORTHWARD EXTENSION OF THE SWEETGRASS ARCH

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ABSTRACT

The stratigraphy of the Sweetgrass arch shows that the earliest known folding occurred between the Mississippian and Jurassic. From Jurassic to the end of Colorado time additional uplift occurred along an axis which corresponds to the position of the present axis, but the plunge of the arch at that time was south and not north as it is now.

The Sweetgrass arch is considered to be a positive element, comparable to the Cincinnati arch with regard to its position and development.

The major uplift of the Sweetgrass arch was produced at the close of the Cretaceous by an increase of folding to the south and a northward extension as a deformational wave, which wiped out the earlier south plunge.

The initial folding of the arch was probably produced by vertical stresses. The final folding was controlled by stresses which were vertical in action, but which were the result of a progressive resolution of horizontal diastrophic stresses from the west. The resolution of these stresses produced tensional conditions on the east flank of the arch which is illustrated by normal faulting and the occurrence of igneous intrusions.

That part of southern Alberta and northern Montana which lies from 40 to 90 miles east of the Rocky Mountain front, may be considered a geologic province, underlain for the most part by gently dipping rocks bowed into a great fold, the Sweetgrass arch.[1] Rising in the Little Belt Mountains, this arch trends west of north into southern Alberta, and then swings to the northeast, finally losing its identity north of the city of Medicine Hat. Over this total extent of 200 miles the width of the arch varies between 40 and 70 miles.

In the summer of 1931 the writer, with the assistance of R. W. Kelly, mapped in detail an area covering six townships, in Ranges 22 and 23 just west of Lethbridge, Alberta. In addition, sufficient well records were obtained, so that the characteristics of the Sweetgrass arch in southern Alberta were fairly well determined.[2]

[1] Eugene Stebinger, "Possibilities of Oil and Gas in North Central Montana," *U.S. Geol. Surv. Bull. 641* (1916), p. 64.

[2] The writer wishes to express his indebtedness to the various oil companies (Hudson Bay Oil and Gas Company, Limited; Parco Oil Company, Limited; The Imperial Oil Company; Canadian Western Natural Gas, Light, Heat and Power Company; Commonwealth Petroleum, Limited; Mayland Oil Company, Limited), operating in this area, and to Col. F. M. Steel of the Supervisory Mining Engineer's Office, Department

STRATIGRAPHY

There is considerable disagreement regarding the nomenclature of the different formations in this area,[3] the chief difficulty arising from the use of local names by early geologists, and a later attempt to change these names to those adopted in other areas. The situation is further complicated if an attempt is made to correlate the sediments of the Plains region with corresponding horizons along the Rocky Mountain front. In preparing the following table the best-known names have been used, although there is considerable uncertainty about some, especially in the Cambrian and Upper Cretaceous.

FORMATIONS OF THE SWEETGRASS ARCH

	Thickness in feet (northern area)
Tertiary	
Willow Creek sandstone and shale	1,000[4]
Upper Cretaceous	
St. Mary River sandstone and shale	1,500[5]
Fox Hills sandstone (Horsethief) (Blood Reserve)	140–375[6]
Bearpaw shales	730
Judith River (Two Medicine) (Mesaverde)	1,300–1,900[7]
{ Pale Beds / Foremost Beds }	

of the Interior, Calgary, for furnishing valuable data. Free use was also made of publications of the Geological Survey of Canada, and the United States Geological Survey.

This paper was written at Cornell University under the direction of Professor C. M. Nevin, to whom the writer is grateful for helpful suggestions and criticisms.

[3] For a complete discussion of the stratigraphy in southern Alberta the reader is referred to the Donaldson Bogart Dowling Memorial Symposium, "Stratigraphy of the Plains of Southern Alberta," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XV, No. 10 (October, 1931), pp. 1123–1291.

[4] The thickness of this formation is an estimate from M. Y. Williams, and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Surv., Can. Mem. 163* (1930), p. 60.

[5] The stratigraphy of the St. Mary has recently been worked out by L. S. Russell, "Stratigraphy and Structure of the Eastern Portion of the Blood Indian Reserve, Alberta," *Geol. Surv. Can. Sum. Rept. 1931*, Part B, pp. 26–39.

[6] The Fox Hill sandstone is a widespread horizon marker between the marine Bearpaw and the continental St. Mary. The term Horsethief has a restricted use in Montana, and Blood Reserve has recently been proposed by Russell, *ibid.*

[7] The Judith River formation was named east of the Sweetgrass arch. It is the approximate equivalent of the Mesaverde of Wyoming and Colorado, the Two Medicine of northwest Montana, and the Pale and Foremost beds of southern Alberta, "Stratigraphy of the Plains of Southern Alberta," *op. cit.*

Clagget shale (Pakowki)	100–350[8]
Eagle sandstone	
{ Upper Milk River } (Virgelle)	300[9]
{ Lower Milk River }	
Colorado shale (Benton) (Alberta)	1,800[10]
Lower Cretaceous	
Blairmore sandstone	350
Unconformity(?)	
Upper Jurassic	
Ellis sandstone and shale	250
Major unconformity	
Mississippian	
(Quadrant formation—not present on the Arch)	
Madison limestone	750–1,100
Unconformity(?)	
Devonian	
Three Forks limestone	4,000[11]
Jefferson dolomite	700[12]
Unconformity	
Cambrian	
Meagher limestone	250–350[13]
Barker shale	700[14]
Flathead sandstone(?)	(?)[15]

Of the four unconformities listed above, the lowest one, at the base of the Devonian, was suggested by Collier.[16] It is probable that

[8] Clagget and Pakowki are equivalent, the former name having priority in Montana.

[9] The Upper and Lower Milk River sandstone of Alberta is the same as the Eagle of Montana, the Lower Milk River being used to designate that division known as the Virgelle in northern Montana.

[10] The lower part of the Colorado shale, which is quite sandy, is called the Blackleaf member by many geologists. The basal part of this member may be equivalent to the Dakota sandstone, as suggested by Bauer and Robinson, *Amer. Assoc. Petrol. Geol. Bull.* 7, No. 2 (1923), pp. 159–78.

[11] These two formations are used as interpreted by Moore, "Stratigraphy of the Plains of Southern Alberta," *op. cit.*

[12] *Ibid.*

[13] It is reported that Cambrian formations have recently been penetrated in southern Alberta and correlated with those in Montana by J. O. G. Saunderson, consulting geologist, Calgary, Alberta.

[14] *Ibid.*

[15] *Ibid.*

[16] A. J. Collier, "The Kevin-Sunburst Oil Field and other Possibilities of Oil and Gas in the Sweetgrass Arch, Mont.," *U.S. Geol. Surv. Bull. 812* (1929), pp. 57–189.

this has a regional significance, since later investigations show the absence of Silurian and Ordovician rocks in southern Alberta.[17] The hiatus at the base of the Mississippian, tentatively suggested by Collier,[18] has not been definitely established as yet. The regional unconformity at the base of the Ellis is of major importance, since Upper Jurassic rocks rest on Mississippian. For instance, in Montana, south of Great Falls, the Quadrant formation of Mississippian age overlies the Madison, but northward over the Sweetgrass arch the Quadrant has not been found; proceeding still farther north the interval increases and Cretaceous rocks rest on Devonian, as shown by Hume in the Fort Norman area.[19] The same relationship is found to the east in Manitoba, where Upper Cretaceous rocks overlie Upper Devonian. More recently Evans[20] has suggested a fourth unconformity which lies between the Blairmore and Ellis, but considers it to be of local extent.

The sedimentary section on the Sweetgrass arch in Montana, from the top of the Virgelle sandstone to the base of the Cambrian, Collier has estimated[21] to have a thickness of 5,600 feet. From the evidence of a deep test in southern Alberta[22] the writer estimates a thickness of 5,750 feet for the same section. Since the variation in lithology is not great from south to north along the Sweetgrass arch, the following remarks apply to the whole area.

Of this total thickness, 45 per cent consists of shales, most of which occur in the upper part of the section; and 42 per cent is represented by limestones, all of which are found in the Paleozoic part of the section. The remaining 13 per cent is composed of sandstones and shaley sandstones. In addition, on the flanks of the arch upward of 5,000 feet of Cretaceous and Tertiary sediments are found which are not now present on the crest. These represent sandstones and sandy shales of continental origin, with the exception of the Bearpaw

[17] P. D. Moore, "Stratigraphy of the Plains of Southern Alberta," *op. cit.*

[18] *Op. cit.*, p. 62.

[19] Geo. S. Hume, "Geology of the Norman Oil Fields and a Reconnaissance of a Part of Liard River," *Geol. Surv. Can. Sum. Rept.* (1922), Part B, p. 59.

[20] C. S. Evans, "Milk River Area and the Red Coulee Oil Field," *Geol. Surv. Can. Sum. Rept.* (1930), Part B., p. 10.

[21] *Op. cit.*

[22] Commonwealth Petroleum, Ltd. Milk River No. 1.

shales which are marine. Although pre-Cambrian sediments are present, so little is known of them in the Plains region that they are here considered as part of the Basement Complex.

Summing up the preceding statements it may be said that the Sweetgrass arch is now covered by sedimentary rocks slightly over a mile in thickness. The upper half of this section is composed of incompetent formations, and the lower half is made up of relatively competent beds. There was probably an additional 4,500 feet of Tertiary and Cretaceous sandstones and shales on the Sweetgrass arch which have since been removed by erosion. This would give a total thickness of 10,000 feet, and if this is compared with the breadth of the arch, the ratio of overburden above the pre-Cambrian to the breadth, would be about 1 to 40.

STRUCTURE OF THE ARCH IN ALBERTA

From the evidence now available it appears that the Sweetgrass arch occupies an old zone of instability which has suffered mild deformation at different times throughout its history. In southern Alberta part of the Upper Madison beds, which are present on the flanks of the arch, have been removed from the top by erosion.[23] Howell[24] also found this to be the case in Montana, where the Madison section over the crest is 400 feet less than on the flanks.

With regard to the Kootenai and Ellis formations, Romine points out[25] that there is also a considerable thinning of these beds over the crest of the arch in Montana. Figure 1 represents an interval map for southern Alberta on which the thickness of the section, from the top of the Virgelle sandstone to the base of the Ellis, is shown. By comparing this with the structural map (Fig. 2), it is evident that the thinnest part of the section corresponds closely to the axis of the arch; that is, disregarding minor effects, the formations from at least Mississippian time to at least the end of Colorado time show distinct thinning over the crest of the arch.

The only place where differential compaction could have been im-

[23] P. D. Moore, *op. cit.*, p. 26.

[24] W. F. Howell, "Kevin-Sunburst Field, Montana," *Structure of Typical American Oil Fields*, Vol. II. (*Amer. Assoc. Petrol. Geol., 1929*), pp. 254–65.

[25] T. B. Romine, "Oil Fields and Structure of Sweetgrass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XIII, No. 7 (July, 1929), pp. 779–97.

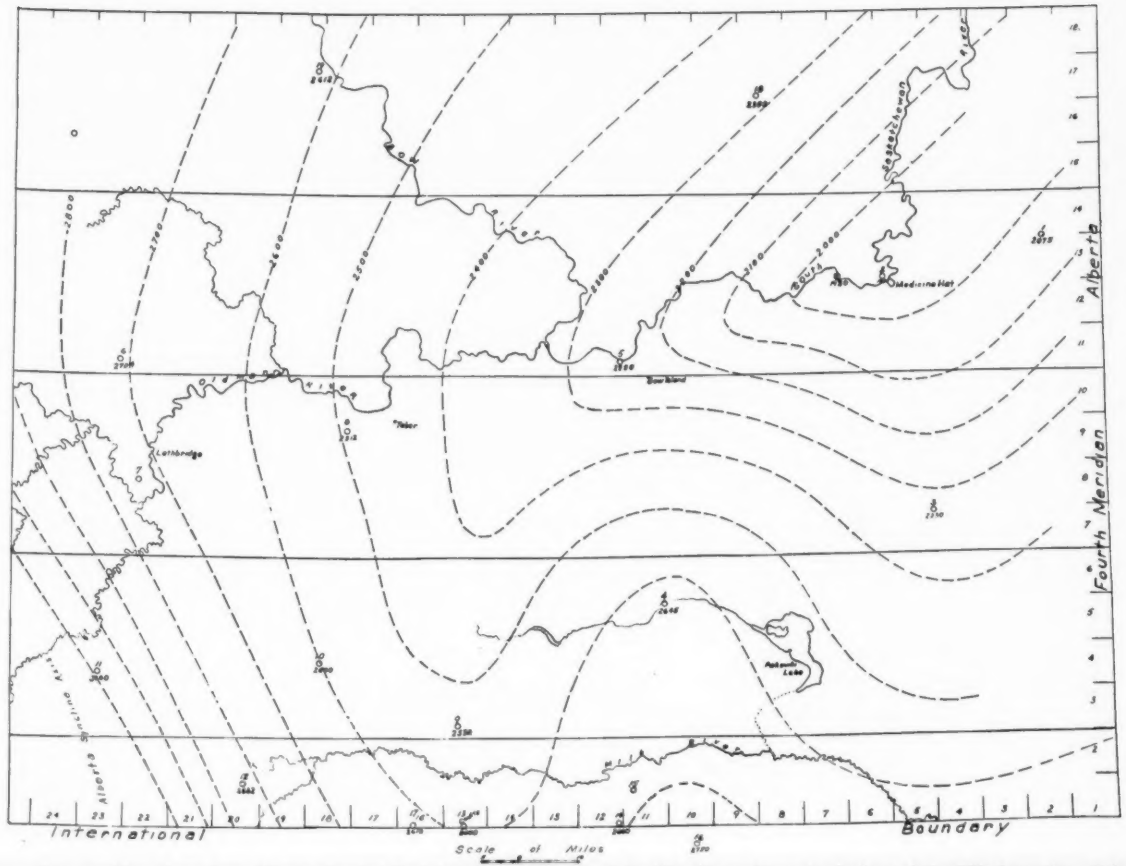

FIG. 1.—Map of southern Alberta showing the interval from the top of the Virgelle sandstone to the base of the Ellis formation. C.I.

portant is on the eroded surface of the Madison limestone. The cavernous nature of this surface and the presence of chert and iron stains as shown by drill-hole data indicate that the Madison surface was considerably weathered. These facts, together with the wide-

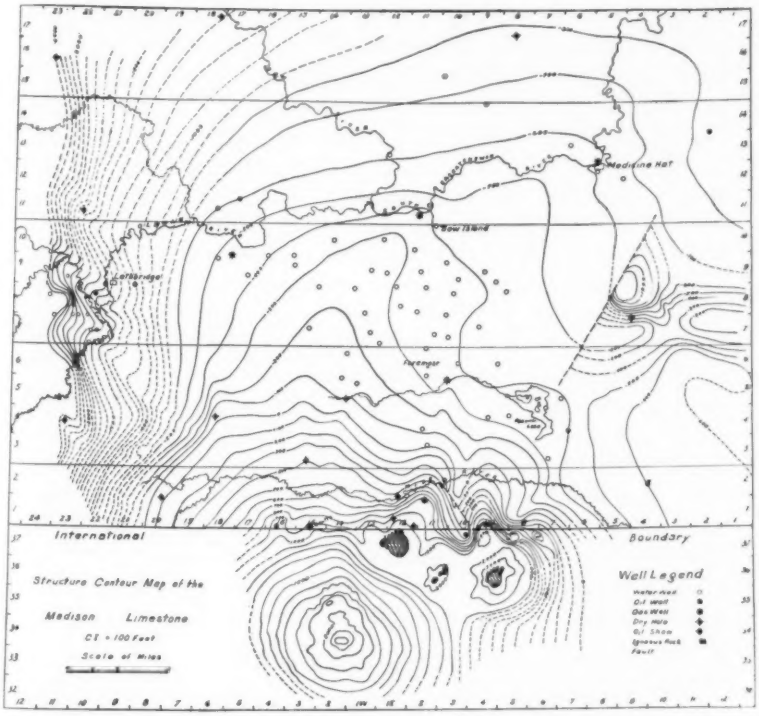

FIG. 2.—Contour map of the present Madison limestone surface. Structure contour of the base of the Ellis formation.

spread evidence of beveling, point to the conclusion that the Madison had a relatively low topographic relief when the shallow-water Ellis formation was deposited. There is little evidence, therefore, that differential compaction over buried topography has here caused any considerable thinning of the section. Moreover, the basal Ellis

is not particularly compactible, since it consists of impure limey sands, and it is in this particular zone that differential compaction must occur if buried topography is going to exert a controlling influence.

Presumably, an important factor in the post-Madison development of the Sweetgrass arch was the slow, and perhaps recurrent, uplift which took place contemporaneously with deposition. The sediments from Ellis to Virgelle were deposited in a shallow-water environment. Numerous glauconite and sandy zones occur in the Ellis, which change to red shales near the top.[26] Carbonaceous shale, red shale, and glauconite are also found in the Blairmore.[27] The marine Colorado shales are sandy, and farther north sandy ripple-marked beds and conglomerates are found in the Cardium sandstone which is a member of this formation. Also, the Virgelle (Lower Milk River) is considered by Evans to be a near-shore marine sandstone.[28]

Throughout this shallow-water section of some 2,600 feet, the thickness over the crest of the arch is approximately 500 feet less than on the flanks (Fig. 1). Since there is no marked unconformity during this period of deposition, and since all the deposits have shallow-water characteristics, the uplifts must have been more or less continuous and of about this order of magnitude. The arch, moreover, did not rise rapidly enough to produce a local profile of depositional equlibrium, for the changes in lithology from east to west across the axis are not significant, and the formations, although showing considerable local variation, are continuous as a whole.

STRUCTURAL DETAILS OF THE ARCH

The contour map (Fig. 2) showing the present attitude of the Madison surface was constructed in part from well data[29] on the overlying Virgelle sandstone, the correct interval between these formations being obtained from the interval map (Fig. 1). This was supplemented by several published and unpublished maps in different parts of the area. This surface does not represent the real struc-

[26] C. S. Evans, *op. cit.*, p. 7.

[27] *Ibid.*

[28] *Ibid.*

[29] Well data secured from oil companies and the Geological Survey of Canada.

ture of the Madison limestone, because erosion of the crest has reduced the true structural relief some 500 feet. The map of course represents the structure of the bottom of the Ellis formation.

The main axis of the Sweetgrass arch plunges north 10° west from the top of the Kevin-Sunburst dome in Montana to a point 30 miles north of the International Boundary in Alberta at the rate of 44 feet per mile. It then swings northeast passing throgh Bow Island and north of Medicine Hat. In this direction the rate of plunge decreases to about 8 feet per mile. East and west from the crest the formations dip away very gently rarely exceeding a rate of 50 feet per mile.

Although the igneous plugs known as the Sweetgrass Hills are not properly a part of the Sweetgrass arch, they illustrate the fact that the greatest uplift may be associated with igneous intrusions of local extent. Their influence does not extend as far as the Kevin-Sunburst dome,[30] yet several prominent noses radiate northward from these hills in such a way as to suggest a connection between igneous intrusion and uplift over a considerable area.

In the eastern part of the area, Townships 5–11 (Figs. 2 and 3), is the Cypress Hills structure. It was first mapped by Dyer[31] who suggested that it is comparable in size with the Kevin-Sunburst dome. His map indicates a rotational fault trending northeast with a maximum throw of about 500 feet. The interpretation given by the writer is that the section lying to the east of this fault has been rotated about a hinge, the center of which is in the lower part of T. 8, R. 5. The downthrown section which takes the form of a basin is north of the hinge, and the maximum throw is about 500 feet. The upthrown block on the south has the form of a truncated anticline, with a maximum throw of about 300 feet. To the east the anticline passes into a saddle, and then emerges on the eastern border of the map in T. 7.

The western flank of the Sweetgrass arch presents an interesting contrast, as it passes into the Alberta syncline with a pronounced thickening of the formations (Fig. 1) and a marked increase in dip. Thus, between the Parco Oil and Gas Company's well, Twin River

[30] Collier, *op. cit.*, pp. 57–189.

[31] W. S. Dyer, "Geological Structure in the Western End of Cypress Hills, Alberta," *Geol. Surv. Can., Sum. Rept.* (1926), Part B, pp. 15–30.

No. 1, Sec. 34, T. 1, R. 20, and Spring Coulee No. 1, Sec. 15, T. 4, R. 23, there is a thickening of 270 feet between the Virgelle sandstone and the Madison limestone in 24½ miles, and an average dip of 97 feet a mile. On this flank of the arch faulting of both reverse and normal types has been observed. The most important fault is a sheared zone on Oldman River, Sec. 31, T. 9, R. 23, where a series of at least fourteen small reverse fault blocks are piled up in a section only a mile in width. Here the Fox Hill sandstone, which, although

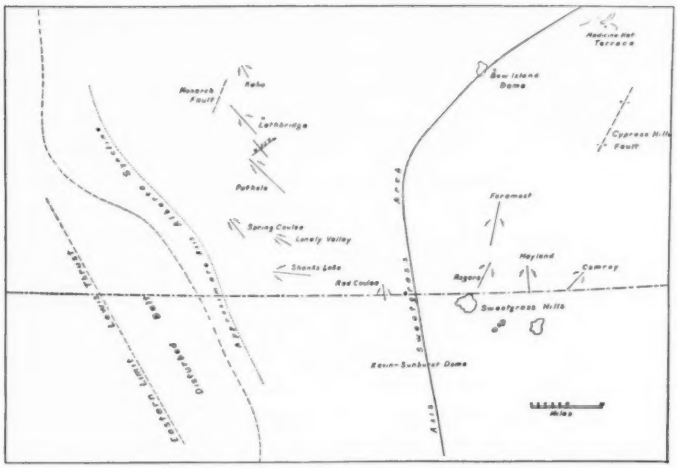

FIG. 3.—Sketch map of the structural trends in southern Alberta and northern Montana.

highly drag folded, is repeated in nearly every fault block, for the most part dips steeply to the west; the fault planes are inclined to the west at high angles of from 50° to 60°, and the sheared zone as a whole trends north 15° east. The total vertical throw is thought to be in the neighborhood of 1,500 feet. Owing to the steep inclination of the fault blocks, and the progressive decrease in throw of the individual faults toward the western part, that edge of the faulted zone is at about the same stratigraphic horizon as the eastern edge. Whether this faulted zone continues to a considerable depth or whether the throw is rapidly taken up by the underlying shales is a matter of

speculation. This sheared zone as a whole indicates the action of strong compressive stresses from the west in at least the upper part of the sedimentary section.

The normal faults on the west flank, although quite numerous, are of small magnitude. A typical example was observed on Oldman River, Sec. 11, T. 8, R. 22. It trends west of north and is of the high-angle normal fault type with a downthrow of about 80 feet on the west side. In Sec. 1, T. 9, R. 22 on the east side of Oldman River another normal fault appears. The trend of this fault as shown by mining operations is to the northeast, the downthrow of 60 feet being on the west.[32] A large number of small normal faults were observed in exposures along Oldman and St. Mary rivers in Ranges 22 and 23, but these were not mapped as they appear to have little structural significance.

By far the most prevalent type of local folding on the Sweetgrass arch is a nose plunging to the northwest. Two exceptions are the structures at Bow Island and Medicine Hat. The former is described as a low dome of 50 feet closure, the latter as a southward plunging nose cut by an east-west trough.[33] Both of these structures contain commercial quantities of natural gas.

The writer mapped two noses in the vicinity of Lethbridge (Fig. 2) which plunge about north 40° west. Two other structures, believed to be similar to the above, are present at Spring Coulee, T. 4, R. 23, and Keho Lake, T. 11, R. 22. Another north-plunging nose is found at Red Coulee, T. 1, R. 16. Several other noses which do not show on a map of this scale are described by Williams and Dyer.[33]

The most prominent structures which fall in this group are the noses which extend northward from the Sweetgrass Hills. For example, from West Butte, just south of T. 1, R. 12, the Foremost anticline plunges north for over 30 miles, while the structural drop over the same distance is about 1,300 feet. East of this is another prominent nose which also plunges north toward Pakowki Lake. Natural gas has been found on both of these structures.

[32] Williams and Dyer, *op. cit.*, p. 88, have described several other faults in this area and elsewhere.

[33] Williams and Dyer, *ibid.*, pp. 114, 118.

REGIONAL STRUCTURE

Figure 3 is a sketch map of the structural trends in southern Alberta and northern Montana, together with the adjacent Rocky Mountain front.

The approximate position of the Lewis fault is shown with a trend of north 30° west. Along this zone the formations have been thrust plainsward for a distance of about 15 miles. Parallel with this, and occupying a zone of from 10 to 25 miles in width, is the Disturbed belt. This distinctive structural feature can be traced along the entire length of the Canadian Rocky Mountain front. The formations in this belt are highly folded and thrust faulted, and in most cases the fault planes dip steeply to the west, but rarely have sufficient throw to expose the Paleozoic beds. The structures in the Disturbed belt are of smaller magnitude, although more intricately folded than those farther west. They parallel the strike of the Lewis thrust fault, i.e., 30° west of north, except in the northeastern part, where the trends swing 50° to 60° west of north.[34] The Disturbed belt ends rather abruptly on its eastern boundary, where it gives way to the Alberta syncline, which may be recognized by an almost complete lack of faulting and the presence of Tertiary deposits. "The Alberta syncline is a direct descendant of the much greater Cordilleran geosyncline from which the Rocky Mountains and foothills arose."[35] The dips, which are much steeper on the west flank, reach as high as 15°. A cross section of the Alberta syncline would be spoon shaped, a characteristic of both the Cordilleran[36] and Appalachian geosynclines.[37]

Just south of the International Boundary is the Kevin-Sunburst dome. This structure, which occupies the highest structural position on the Sweetgrass arch in this area, has a closure of at least 700 feet and is roughly circular in outline with a diameter of about 25 miles.

[34] J. S. Stewart, "Geology of the Disturbed Belt of Southwest Alberta," *Geol. Surv. Can. Mem. 112* (1919), p. 48.

[35] Theo. Link, "The Alberta Syncline," *Amer. Assoc. Petrol. Geol. Bull.*, Vol. XV, No. 5 (May, 1931), pp. 491–507.

[36] *Ibid.*

[37] Paul H. Price, "The Appalachian Structural Front," *Jour. Geol.*, Vol. XXXIX (1931), pp. 24–44.

It has been mapped in considerable detail owing to its commercial value in the production of oil.

STRUCTURAL DEVELOPMENT OF THE SWEETGRASS ARCH

One of the characteristic structures associated with two of the great mountain systems in North America is the development of a broad fold on the continental side of the mountain front. About 200 miles west of the Appalachian structural front is the Cincinnati arch, and about 80 miles east of the Rocky Mountain front is the Sweetgrass arch.

Both of these folds originated early in the development of the geosynclines of which they formed a part. The beginning of the Cincinnati arch is recognized in the Ordovician and it continued to be a positive element in the Appalachian geosyncline until the end of Pottsville (Pennsylvanian) time, at which time the final folding took place. This time also corresponds to the orogeny of the Appalachians. The Sweetgrass arch has a similar history. The earliest known folding took place between Madison and Ellis time (Mississippian and Upper Jurassic), and from then until the end of the Cretaceous it appears to have been a positive element in the Cordilleran geosyncline. The final deformation occurred soon after this, corresponding to the period of deformation and mountain building in the Rocky Mountain province.

The post-orogenic uplift of the Rocky Mountains must have affected the Sweetgrass arch, since this whole area was elevated at that time. What proportion of its present attitude we may attribute to this cause is difficult to say, although the earlier stresses which folded and faulted the Rocky Mountains, as will be shown later, seem to have been a more dominant factor.

The Alberta syncline, which is complementary to the Sweetgrass arch, should not be confused with the much greater and older Cordilleran geosyncline. As shown by Link[38] the deepest part of the Cordilleran trough moved eastward with each successive period of deposition. Its history dates back to pre-Cambrian time and it is, of course, a much older and greater structural element than the Sweetgrass arch. In the first stages of folding, therefore, the trend

[38] *Op. cit.*

of the arch was probably controlled by the trend of the geosyncline of deposition lying to the west.

When the deeper part of the Cordilleran geosyncline was distorted by easterly directed stresses and the Rocky Mountains were folded and faulted, the presence of this arch to the east must have had a strong influence on the character of deformation on the area between. It is probable that the Alberta syncline was to some extent controlled by the presence of the Sweetgrass arch, for where the arch approaches closer to the Rocky Mountain front, the Alberta syncline is much steeper and better defined. Northward, where the Sweetgrass arch loses its identity, the Alberta syncline is less prominently developed. A similar syncline lies between the Appalachian Structural front and the Cincinnati arch, but it is not so well defined owing to its greater breadth.[39]

It has already been pointed out that Figure 1 represents the amount of folding that occurred between Ellis and Virgelle time. Considering the whole question from a somewhat different angle it is also possible to use this map as a representation of the attitude of the Madison surface (or the bottom of the Ellis) at the time of deposition of the Virgelle sandstone. If this is done, it is apparent that the configuration of the Sweetgrass arch in Alberta, as expressed on this surface at the close of Colorado time, was an arch whose axis corresponded very closely with the position of the present axis, but whose direction of plunge was south and not north as it is now.

From Medicine Hat the basal Ellis must have plunged southwest along the crest for 56 miles at a rate of 8 feet per mile, and then must have swung south, the rate of plunge decreasing to 4 feet per mile. The total south drop over this distance of 110 miles was 700 feet; that is, in Virgelle time the base of the Ellis was 700 feet lower at Coutts than it was at Medicine Hat.

The present attitude of the arch shows the reverse conditions (Fig. 2). The base of the Ellis is now 1,600 feet higher at Coutts than it is at Medicine Hat. After Virgelle time, therefore, there was an elevation of the arch as a whole which amounted to 2,300 feet at the International Boundary and to about 3,000 feet on top of the

[39] J. B. Richardson, "Structure-Contour Maps of the Pittsburg-Huntington Basin," *Geol. Soc. Amer. Bull.*, Vol. XXXIX, No. 2 (1928), pp. 543–53.

Kevin-Sunburst dome. During this period of elevation the amount of east-west folding which was about 500 feet in the vicinity of Medicine Hat during Virgelle time increased to about 1,600 feet at the International Boundary, and to about 2,800 feet across the Kevin-Sunburst dome. From this we may conclude that the reversal of the south plunge was not caused by a simple uniform regional tilt, but rather by an increase in the folding to the south, and a northward extension as a deformational wave. By comparing Figures 1 and 2 we see that this deformational wave completely dominated the former south plunge where it was relatively gentle near the International Boundary; but, as it progressed north the reversal is not so marked and the north plunge died out where it encountered the increasing magnitude of the earlier south plunge. Somewhere northeast of Medicine Hat one might therefore expect to find a reversal of dip where the earlier south plunge had overcome the northward progress of the deformational wave. If the anticlinal nature of the Sweetgrass arch extended beyond such a point, the resulting structure would be a saddle.

CHARACTER OF DEFORMATION

The Sweetgrass arch originated toward the close of the Paleozoic, during a broad differential upwarp which affected a large part of the Cordilleran geosyncline. Most of the sedimentary record at the time of these movements is covered; but it would seem reasonable to infer that gentle warping over such wide areas may not have been controlled by compressive stresses. The continued rise of the Sweetgrass arch from Ellis to Virgelle time would also indicate that vertical adjustments were still active. The vertical component of a horizontal stress in the initial stages of folding is usually small, and when we consider that this early folding produced a structural difference of only about 900 feet across an arch whose breadth must have been approximately 75 miles, it is far easier to picture this strain as resulting from dominantly vertical adjustments.

When we come to the great deformation at the close of the Cretaceous, we should be able to find considerable evidence of the direction and character of the stresses operating, since the minor structures of the Sweetgrass arch and the major regional structures should furnish clues.

At this time of mountain building strong easterly directed stresses prevailed in the Rocky Mountains and foothills, as evidenced by the Lewis Thrust fault and the Disturbed belt. The Alberta syncline between the Disturbed belt and the Sweetgrass arch was folded with a steeper dip on the west side. The Sweetgrass arch was elevated and the dip of the west flank was steepened as compared with the east flank, indicating that horizontal stresses extended at least to this area. The major part of this stress was, of course, taken up by the failure of the rocks in the Disturbed belt and along the Lewis and other similar faults. The folding of the Alberta syncline and the steepening of the west flank of the arch no doubt relieved the remaining part of this easterly directed stress.

Certain minor structures on the west flank of the Sweetgrass arch show evidence of compressive stresses. For example, the regularity of the trends in the zone of folding, which extends from Shanks Lake to Keho Lake (Fig. 3), is thought to be an expression of distorting forces from the west. The zone of thrust faults on Oldman River, T. 9, R. 23, is an additional proof of the activity of such stresses.

Over the central and eastern portion of the Sweetgrass arch, however, there is little evidence of compressive folding. In other words, these easterly directed stresses were entirely relieved before reaching the east flank of the arch.

When tangential stresses encounter a fold which is partly developed, as the Sweetgrass arch was at the time of the Rocky Mountain deformation, it is mechanically possible for a considerable portion of the stress to be resolved into vertical components. The resolution of such a stress is progressive and as the arch rises higher there is a relative increase in the vertical component. This is in accord with what has been said regarding the type of failure on the Sweetgrass arch, since it merely requires the vertical component to be large enough to lift the arch progressively as pressure was applied from the west. No doubt the controlling formations in raising and supporting the arch were the competent beds of the pre-Cambrian and Paleozoic, for, as pointed out in the preceding pages, the upper part of the sedimentary section is too thin and incompetent either to transmit the stress or support the arch.

The frequent association of high-angle normal faults and mono-

clinal flexures with broad uplifts is well established. The Cypress Hills fault in the eastern flank of the Sweetgrass arch is believed to be of this nature. Its trend approximately parallels the axis of the arch and its greatest displacement is about 500 feet with the downthrown side on the east. It was no doubt caused by tensional rather than compressive stresses. This is what one might expect to find on the east side of a rising arch that was affected by stresses from the west, for, if the horizontal stresses were resolved into vertical components, and entirely relieved by uplift, tension would result on the east flank.

Moreover, this distribution of stresses might explain the position of the igneous cores of the Sweetgrass Hills. Other things being equal such igneous intrusions would occur at those places where there was the least resistance to flow. Thus tensional conditions on the east side of the Sweetgrass arch would be favorable for igneous activity. It should also be noted that these intrusions occur opposite the Kevin-Sunburst dome where the greatest amount of structural relief is found.

It has been suggested by Collier[40] that the Kevin-Sunburst dome might be the surface expression of a large deep-seated laccolith and several other writers have considered it to be the result of compressive folding, and Williams and Dyer[41] applied the latter idea to the northward extension of the Sweetgrass arch in Alberta. As pointed out in the preceding pages compressive stresses no doubt had an influence on the attitude of the west flank of the Sweetgrass arch, but it is believed by the writer that the stresses that really controlled the uplift were dominantly vertical in their action and that the initial arch, having once been established in the Paleozoic, has been intermittently rejuvenated.

[40] *Op. cit.* pp. 57–189.

[41] Williams and Dyer, *ibid.*, p. 86.

THE CARBONIFEROUS-PERMIAN DILEMMA[1]

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ABSTRACT

The extreme diversity of opinion as regards the position of the boundary between the Carboniferous and Permian has led to a review of the stratigraphy in the type areas of those systems, together with a survey of some of the more important works on the critical areas of "Upper Carboniferous" and "Lower Permian" marine deposits throughout the world. A graphic comparison of various delimitations shows that the boundary has oscillated throughout the Moscovian, Uralian, and Artinskian stages; that is, in the most prevalent of American terminologies, from the base of the "Pennsylvanian" to well within the "Permian." Confusion would be eliminated, and greater precision in correlating strata and events would be attained by a more extended use of the European stage designations than by continuing to employ terms of such variable and ambiguous sonnotation as "Carboniferous" and "Permian."

INTRODUCTION

As one of the objectives of a study of the McCloud limestone of northern California,[2] the writer hopes to correlate that formation with other chronologically equivalent Anthracolithic strata of Eurasia and North America. During the preliminary stages of the investigation this seemed attainable. But further study shows that this limestone occupies a position in the geologic column such that many authorities would unhesitatingly assign it to the Pennsylvanian or Upper Carboniferous, whereas others, perhaps the majority, would call it Permian. Exactly where the Carboniferous-Permian boundary should be placed, therefore, constitutes a problem of primary importance to the writer and to many others who, like Berry,[3] in a recent discussion of an Uralian plant-bearing horizon in Bolivia, are in doubt as to which of the two system names should be employed.

The purposes of this paper are to show graphically the diversity

[1] Read before the Cordilleran Section of the Geological Society of America, Los Angeles meeting, April 7, 1933.

[2] H. E. Wheeler, "Fusulinids of the McCloud and Nosoni Formations of Northern California" (Abstract), *Pan-Amer. Geol.*, Vol. LVIII, No. II (1932), p. 64; *Bull. Geol. Soc. Amer.*, Vol. XLIV (1933), p. 218.

[3] E. W. Berry, "Carboniferous Plants Interbedded in the Marine Section of Bolivia," *Amer. Jour. Sci.*, Ser. 5, Vol. XXV, No. 145 (1933), pp. 49–54.

of opinion with regard to the Carboniferous-Permian boundary, and to suggest a means whereby correlations and age assignments can be made without adding further perplexities to the existing confusion. It is not the aim of this paper to delimit the Carboniferous and Permian systems. Rather, the writer desires to promote the use of the European marine stages, which have a proved value as standards in interregional correlation, thereby avoiding the ambiguity of the terms "Carboniferous" and "Permian."

THE BOUNDARY PROBLEM

The continuous shifting of opinions in the past regarding the line of demarcation between the Carboniferous and Permian (Fig. 1), together with a general disagreement on that subject among the more recent workers, makes it necessary that present-day correlations, in order that they may be of lasting value, be based upon a standard—a common ground upon which all workers should be able to meet and agree. In searching for that standard, one is naturally led to the original definition of the Carboniferous system by Phillips,[4] and of the Permian by Murchison, de Verneuil, and Keyserling.[5]

A review of the stratigraphy of the type section of the Carboniferous reveals a series of limestones (largely marine), overlain by the Millstone Grit (marine and continental), which in turn is superceded by the Coal Measures[6] (largely continental). This well-defined system is underlain by the Devonian Old Red sandstone and is overlain by the New Red sandstone. Theoretically, on the basis of its clarity and priority of definition, the Carboniferous system should constitute a standard division of the geologic column; practically it does not, as will be shown in the following pages.

Similarly, one would naturally suppose that the Permian system, as originally defined, should suffice as another integral part of the standard column. A review, however, of the work of Murchison, de Verneuil, and Keyserling discloses a marked inconsistency. Those

[4] W. Phillips, *Geology of Yorkshire* (1836).

[5] R. I. Murchison, E. de Verneuil, and Count A. von Keyserling, *Geology of Russia in Europe and the Ural Mountains*, Vol. I (1845), pp. 137–228.

[6] Émile Haug states (*Traité de Géologie*, Part II [1911], p. 764) that the Upper Coal Measures are without doubt equivalent to the beds at the extreme base of the Stephanian, which in turn are generally correlated with the Lower Uralian.

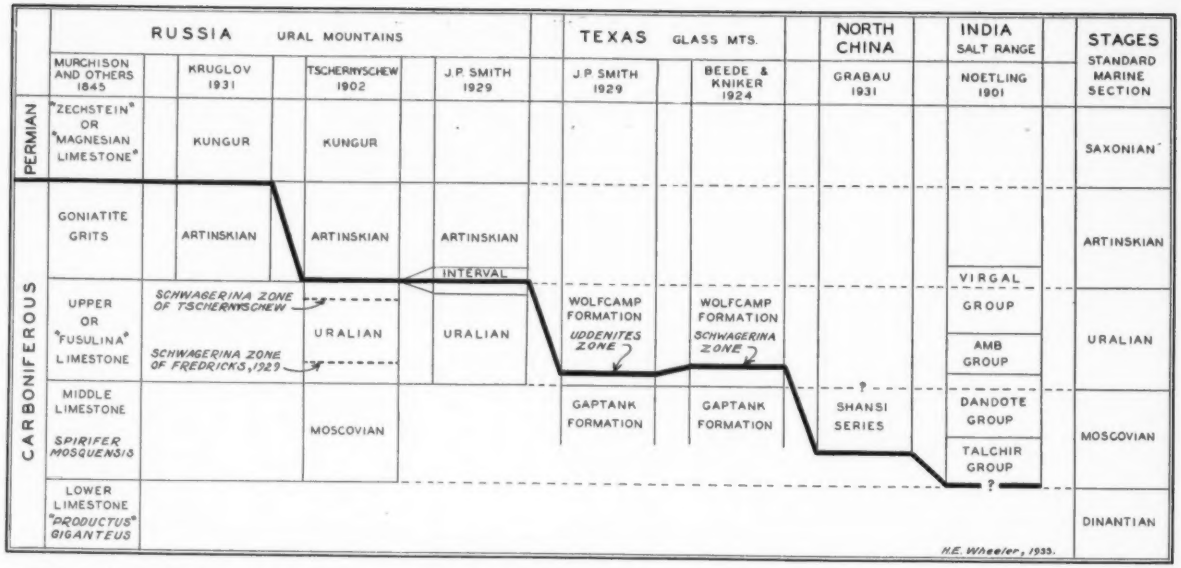

FIG. 1.—Chart showing the stratigraphic position of the Carboniferous-Permian boundary between the marine units, according to various authorities. The horizontal dashed lines illustrate the writer's opinion of the stratigraphic position of the stage boundaries in regions other than Russia.

authors state:[7] "In a word, therefore, our Permian system embraces everything which was deposited between the conclusion of the carboniferous epoch, and the commencement of the Triassic series." On a later page of the same work[8] the following statement may be read: "The oldest beds of this system [Permian], or those of the western slopes of the Ural Mountains, which succeed the upper carboniferous strata [Artinskian], are well developed to the east of the city of Perm, on the banks of the rivers Sylva, Babka, Sira and Gromotucha, ..."

The two preceding statements are conflicting, because the so-called "upper carboniferous strata," which underlie the Permian, as defined in the latter statement, are Artinskian and are younger than any strata, both marine and non-marine, of the typical Carboniferous section in England; and, therefore, according to the premise of the first statement, these beds must necessarily be included in the Permian, since they were deposited during a part of the interval between the close of the Carboniferous and the commencement of the Triassic.

To add further complexities to the problem, the uppermost beds of the typical Carboniferous in England, as stated above, are terrestrial, and thus cannot be correlated readily with the marine deposits of Continental Europe. Furthermore, the possibility of correlating precisely the non-marine strata of the typical Carboniferous with any of the non-marine deposits of the Continent seems doubtful, since the more authoritative recent paleobotanists are noncommittal in their opinions regarding the correlation of the Anthracolithic plant-bearing horizons. So much for the problems arising directly from the original definitions.

The proposed solutions to the dilemma have been many. Most of the Russian geologists in the past have arbitrarily agreed that the base of the Permian should be placed at the base of the Artinskian stage, which is the so-called "upper carboniferous" of Murchison, de Verneuil, and Keyserling.

Beede and Kniker[9] have regarded the lower occurrences of the cos-

[7] *Op. cit.*, pp. 140–41. [8] *Ibid.*, p. 142.

[9] J. W. Beede and H. T. Kniker, "Species of the Genus *Schwagerina* and Their Stratigraphic Significance," *Univ. Tex. Bull.*, No. 2433 (1924), p. 78.

mopolitan fusulinid *Schwagerina* as presenting the lowermost of the Permian deposits. The acceptance of that excellent zone fossil as a marker for the base of the Permian would lower the system to near the base of the Uralian[10] in Russia, and to the lower part of the Wolfcamp formation in west Texas.

J. P. Smith[11] believed that the first appearance of the ammonoid genus *Uddenites* and its associated fauna introduces the Permian period. This lowers the base of the Permian to a position even below the Schwagerina zone, although it is obvious from his discussion that he did not intend to include the Uralian in the Permian. Smith thought that the Uddenites zone fauna of the lower Wolfcamp formation represents a transitional stage between the Uralian and Artinskian, arguing that the primitive medlicottoid *Uddenites* is a later development than any known Uralian form, and that it is distinctly older than, and probably ancestral to, "the Medlicottiinae that mark the Permian everywhere."

Smith writes as follows:

> Highly specialized *Propinacoceras*, *Artinskia* and *Medlicottia* do not come into being all at once and there is nothing in the Uralian even remotely approaching them.
>
> . . . . *Uddenites* is a primitive medlicottoid quite as specialized as could be expected at the base of the Permian.
>
> The fauna [lower Wolfcamp] is clearly transitional from the Uralian stage of development to that of the Artinsk.

If it be true, as Smith believed, that *Uddenites* is a post-Uralian genus, the value of either these ammonoids or that of *Schwagerina* as interregional zone markers automatically meets with failure, since the Foraminifera appears in the lower type Uralian, and yet it is found above the Uddenites zone in the Glass Mountains section. However, this discrepancy is cleared by the application of data set forth in Fredricks'[12] recent revision of the type Uralian, wherein

[10] T. Tschernyschew, in his description of the Uralian section (*Mem. Com. Géol. Russe* [1902], p. 435), places the Schwagerina zone at the top of the section. However, in a recent restudy of the type Uralian, G. N. Fredricks (*Centralblatt für Min. Jahrg.* [1929], p. 549) finds that *Schwagerina* is characteristic of the Omphalotrochus zone near the base of the stage.

[11] J. P. Smith, "Transitional Permian Ammonoid Fauna of Texas," *Amer. Jour. Sci.*, Vol. XVII (1929), pp. 63–66.

[12] G. N. Fredricks, "Die Trogkefelschischten und ihre Analogen im Ural," *Centralblatt für Min. Jahrg.* (1929), p. 549.

he reports *Medlicottia artiensis* Grabau (a descendant of *Uddenites*) from the Upper Uralian. It is inevitable, then, that *Uddenites* represents an earlier Uralian or perhaps even pre-Uralian stage of development, but as yet not found at the type section. Thus, for the first time, it is now possible that both *Schwagerina* and *Uddenites* may be regarded as chronologically valuable genera.

Grabau[13] would not only include all the Uralian in the Permian, but, on the basis of faunal affinities, also the Shansi series of North China which he regards as pre-Uralian.

M. B. Kruglov,[14] of the Academy of Sciences of Leningrad, is of the opinion that some of the lower beds of the Artinskian are synchronous with the Schwagerina zone (of Tschernyschew). This view, of course, is in contrast with that of others who believe there is a break between the Artinskian and Uralian. It is of interest to note that Kruglov would begin the Permian with the Kungur, returning to one of the above-mentioned concepts set forth in the original definition of the system; i.e., with the strata which overlie the Artinskian.

In the Salt Range of India, Noetling[15] begins Permian sedimentation with the Talchir group. The Amb group, which lies 650 feet above the base of the Talchir, is correlated by Tschernyschew[16] and Grabau[17] with the Omphalotrochus beds of the type Uralian. Thus, on the basis of the stratigraphic thickness of the strata intervening between the bases of the Talchir and Amb, if the Permian of India is introduced by the former, as Noetling postulates, the Carboniferous-Permian boundary must necessarily be lowered to a position close to the base of the Moscovian. This inference is in accord with Tschernyschew's[18] correlation of the Talchir and Dandote, which underlie the Amb, with the Moscovian of the eastern slopes of the Urals.

[13] A. W. Grabau, *Permian of Mongolia* (1931), pp. 531–32.

[14] M. B. Kruglov, personal communication to W. Y. Penn, December 24, 1931, as treated in Penn's M.A. thesis, "Upper Pennsylvanian Fossils of the Sacramento Mountains, New Mexico" (Stanford University, 1932).

[15] F. Noetling, "Beiträge zur Geologie der Salt Range, insbesondre der permischen und triassischen Ablagerungen," *Neues Jahrb. für Min., Beilage-Band*, Vol. XIV (1901), table opp. p. 416.

[16] T. Tschernyschew, "Die Obercarbonischen Brachiopoden des Ural und des Timan," *Mem. Com. Géol. Russe* (1902), p. 728.

[17] *Op. cit.*, p. 426.

[18] *Op. cit.*, p. 728.

THE STAGE AS A STANDARD IN STRATIGRAPHY

In Europe it has been the practice to subdivide the systems into stages, which serve as type stratigraphic units throughout a greater part of the geologic column. Fortunately, a large portion of the marine stages, especially those of the Mesozoic and early Tertiary, have a proved value in interregional correlation. These smaller marine units are equally adaptable to the Anthracolithic. Many of the recent researches have illustrated the extended geographic distribution and limited stratigraphic range of the faunas occurring in the stages of the late Paleozoic. For instance, Demanet[19] has recognized the occurrence of the *Gigantella latissima* and *Gigantella gigantea* subzones of the Upper Dinantian of England, France, Belgium, Austria, Poland, Czechoslovakia, Russia, and elsewhere; and he has identified the two species of *Gigantella*, together with *Pustula punctata* (Martin) and other forms characteristic of those subzones, from the Baird formation of northern California, where these species have the same stratigraphic relationships as they do throughout Europe. Packard[20] has described the occurrence of the Baird fauna from the south side of the Ochoco Range in central Oregon. At this locality *Gigantella latissima* (Phillips) and *Striatifera striata* (Fischer) represent the upper of the same two subzones. Either *Gigantella gigantea* (Phillips) or *G. latissima*, according to Girty,[21] is present in Montana, and the former near Cape Lisburne, Alaska.[22]

To cite a single example from the Uralian, Beede and Kniker[23] have shown the distribution of the Schwagerina zone throughout the Northern Hemisphere. Their conclusions are strengthened by Fredricks'[24] discovery that the zone of abundant schwagerinids is the same as the zone of *Omphalotrochus whitneyi* Meek in the Lower Uralian, since those two forms are now known to be associated in

[19] F. Demanet, Royal Museum of Natural History of Belgium, personal communication, May, 1932.

[20] E. L. Packard, "Contributions to the Paleozoic Geology of Central Oregon," *Contr. Pal. Carnegie Inst.*, No. 148 (1932), pp. 111–13.

[21] G. H. Girty, "Relations of Some Carboniferous Faunas," *Proc. Wash. Acad. Sci.*, Vol. VII (1905), p. 3.

[22] E. de K. Leffingwell, "The Canning River Region, Northern Alaska," *U.S. Geol. Surv. Prof. Paper 109* (1919) (Girty's statement on pp. 110–11).

[23] *Op. cit.*

[24] *Op. cit.*, p. 549.

North America, not only in the basal McCloud limestone of northern California, but also in the Providence Mountains[25] of the southeastern part of the state. It is also worthy of note that a mechanically worn limestone boulder from a Triassic conglomerate in central Oregon[26] contains both *Schwagerina* and *Omphalotrochus whitneyi*.

These illustrations are designed to show that the Dinantian and Uralian stages contain faunal elements valuable for purposes of correlation of widely separated formations. Similar illustrations would show that the other marine stages of the late Paleozoic contain equally useful elements.[27] Further, the positions and limits of the stage zones and subzones have been more or less precisely determined; the stages themselves are thus more definite stratigraphic units than are the systems. The European marine stages are advantageous for two additional reasons: first, since they are smaller units than the systems, they reduce the magnitude of possible error in the interpretation of age designations; e.g., "Lower Dinantian" is a more precise term than "Lower Carboniferous"; and, second, by the adoption of the stage as a standard in stratigraphy, the ambiguity of the terms "Carboniferous" and "Permian" would be avoided.

SUMMARY AND CONCLUSIONS

The illustrations cited in the discussion of the boundary problem have shown the diversity of opinion with regard to the stratigraphic position of the line of demarcation between the Carboniferous and Permian. A review of the original definition of the Permian by Murchison, de Verneuil, and Keyserling has again brought to mind the fact that the statements of those authors are contradictory. A review of the later works has shown that confusion has arisen through the difficulties in making correlations between the type

[25] J. C. Hazzard, University of California, personal communication, November, 1932.

[26] E. T. Schenk, Stanford University, California, personal communication, January, 1933.

[27] Charles Schuchert, in his "Review of the Late Paleozoic Formations and Faunas" (*Bull. Geol. Soc. Amer.*, Vol. XXXIX [1928], p. 772), has aptly expressed the appropriateness of selection of the types for the stages of the late Paleozoic. In his discussion of Anthracolithic events, Schuchert states: "The dating of these phenomena begins in the practically complete marine and land records of the Upper Carboniferous and Permian of Russia, which have long been recognized as 'the starting point for the correlation of similar deposits in other countries.' "

sections of the systems, together with the inevitable miscorrelations between the strata of other widely separated regions. The graphic representation on the accompanying chart of the relative positions of the dividing line between the Carboniferous and Permian, as presented in each of the above-cited works, gives a vivid picture of the oscillation of opinions concerning that boundary throughout the Moscovian, Uralian, and Artinskian stages.

The disagreement is augmented by the failure of many workers to realize that the problem is manifold; i.e., biologic, stratigraphic, diastrophic, and geographic. Much has been written on the Carboniferous versus the Permian aspect of faunas throughout the world. Not uncommonly does one read statements similar to the following: "Because the fauna of these strata is more closely related to those of the Carboniferous than to those of the Permian. . . . ." Or, "In view of the Permian affinities of this fauna. . . . ." Such statements are usually meaningless and vague, since the length of the measuring rod is not standardized and, in most cases, can be ascertained only with difficulty. It is obvious that the paleontologic relationships between geographically separated faunas will always remain subject to several interpretations. It should be equally evident that the elements of the geologic time scale must be based upon standard stratigraphic units and *not* upon intangible and ever changing conceptions of biologic relationships, which are colored by individual opinion regarding the limits of periods.

In conclusion, upon consideration of the adaptability of the European marine stages to world-wide correlation, and in view of the poorly defined and loosely used terms "Upper Carboniferous" and "Lower Permian," in order to avoid further confusion, it is recommended that we follow the lead of the modern students of Mesozoic and early Tertiary stratigraphy, and use as standard stratigraphic units the European marine stages. Or, if the establishment of synchrony between widely separated regions is impossible, correlations should be based upon any local stratigraphic series; in fact, this latter method is preferable when interregional correlations are doubtful. And, finally, it should be added that until there is some agreement on the problem of boundary controversies, the establishment of chronologic position in terms of "Carboniferous" and "Permian" should by all means be avoided.

THE SO-CALLED BRANCH IMPRESSIONS OF *CALLIXYLON NEWBERRYI* (Dn) ELKINS AND WIELAND AND THE CONDITIONS OF THEIR PRESERVATION

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ABSTRACT

Long, slender carbonized plant impressions formerly regarded as jointed stems are common in the Antrim, New Albany, and Ohio shales. Dawson referred them to *Calamites inornatus* and White to *Pseudobornia*, but recent investigations show their identity with *Callixylon newberryi*. The transverse markings resembling nodes are similar to cracks produced in weathered plant débris along lake shores. It is believed that these fossils simulating jointed stems in the black shales were formed from weathered fragments of stranded logs along the shores of lakes and bays in which the black shales were deposited.

Carbonized plant remains in the Antrim, New Albany, and Ohio shales which present the superficial appearance of jointed stems have been objects of considerable interest and speculation ever since their discovery. In a recent account the author discussed these fossils in some detail and cited anatomical evidence showing their identity with *Callixylon newberryi*.[1] At that time, however, no doubts were entertained concerning the "nodal" interpretation of the crosslines, although certain difficulties were fully appreciated. It was merely assumed that the external morphology of *C. newberryi* presented features different from plants with which we are now familiar and that material clearing up this particular difficulty would be discovered later.

At the same time attention was called to the fact that Sir William Dawson applied the name "*Calamites inornatus*" to these fossils because of their apparent resemblance to the jointed stems of that genus. An examination of Dawson's figure,[2] however, shows clearly that his specimen from the Genesee shale along Cayuga Lake, New York, upon which the figure was based, was something else. It shows

[1] C. A. Arnold, "On *Callixylon newberryi* (Dn) Elkins and Wieland," *Contr. Mus. Paleon. Univ. Mich.*, Vol. III, No. 12 (1931), pp. 207–32.

[2] J. W. Dawson, "On the Flora of the Devonian Period in North-Eastern America," *Quar. Jour. Geol. Soc. London*, Vol. XVIII (1862), pp. 296–330, Fig. 56, Pl. XVII.

nodal lines extending completely across the breadth of the impression and the very regular longitudinal furrows do not alternate at the nodes as in *Calamites*. In this latter respect it resembles *Asterocalamites*. Jongmans[3] calls attention to the fact that many authors consider it conspecific with *Asterocalamites scrobiculatus*. Even from the very incomplete figure it seems clear that the Antrim shale material is different from Dawson's specimen. In the same account Dawson mentioned fossils from the black shales at Kettle Point, Ontario, which he considered to be the same thing and which are without doubt the same as the material from the Antrim shale on the opposite shore of Lake Huron. But he also stated that these latter specimens were obscure and he made no attempt to figure or describe them in detail. So it seems entirely probable that, while Dawson's type specimen of *Calamites inornatus* is a true calamitean form, the material from Kettle Point which he referred to this species really belongs to *Callixylon newberryi*.

White (quoted by Prosser[4]) referred similar specimens from the Ohio Shale to Nathorst's genus *Pseudobornia*.

Berry[5] recently described some very interesting specimens from the Ohio shale, and in speculating upon the nature of the so-called "nodes" recalled an opinion expressed by Professor A. C. Seward that these lines are shrinkage cracks in preservation. Berry did not entertain this view seriously, but recent studies based upon a considerable amount of material from the northern part of the lower peninsula of Michigan have convinced the writer that Professor Seward's interpretation is correct.

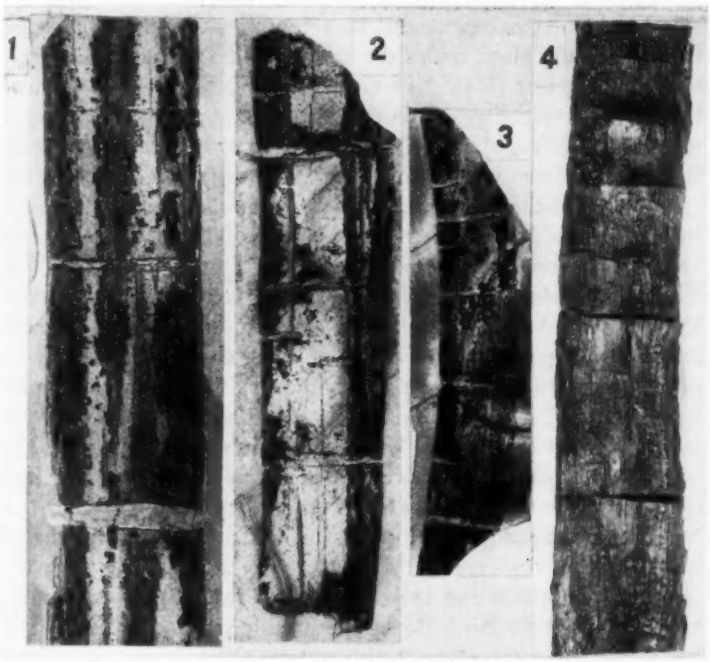
These fossils (Figs. 1–3), which can be seen in almost any exposure of the Antrim, New Albany, and Ohio shales, are linear imprints covered with finely fractured coal. They are marked with rather irregularly spaced lines, the so-called "nodes." Usually the specimens are straight, but they may be slightly curved (Fig. 3). They range from $\frac{1}{2}$ inch to 10 inches in width, but specimens 1 or 2 inches wide

[3] W. Jongmans, *Fossilium Catalogus II, Plantae, Pars 5, Equisetales IV* (Berlin, 1915).

[4] C. S. Prosser, "The Devonian and Mississippian Formations in North-Eastern Ohio," *Geol. Surv. Ohio*, Ser. 4, Vol. XV (1912).

[5] Willard Berry, "A Remarkable Specimen of *Callixylon newberryi* (Dn) Elkins and Wieland from the Ohio Shale," *Ohio Jour. Sci.*, Vol. XXXII, No. 4 (1932), pp. 385–88.

are the most common. Their determinable length is usually limited to the diameter of the shale slabs, which is seldom more than 3 feet. Most of the specimens are 1 or 2 feet long.



FIGS. 1, 2, AND 3.—Carbonized material of *Callixylon newberryi* from the Antrim shale near Alpena, Michigan. ×7/18.

FIG. 4.—Fragment of weathered vegetable débris from shore of Lake Huron. The crosscracks produce a pattern similar to that in Figs. 1–3. Natural size.

The margins of the impressions in the Antrim shale are mostly straight and parallel, although slight irregularities sometimes show. The crosslines, or "nodes," are merely interruptions in the continuity of the coal and the spaces between are filled with shale. Some of the very wide "nodes" have a lateral extent of $\frac{1}{2}$ inch, and the very narrow ones are merely fine lines. The spacing of the "nodes" can best be defined as subregular. They are seldom more than 2 inches

apart, but are frequently much less, and some of them extend but part way across the impression (Figs. 2 and 3).

The nature of these "nodes" presents serious difficulties in interpreting these fossils as stems. The nodes of a stem are the points of attachment of the leaves and the arrangement is orderly. In the fossils from the black shales the spacing is too irregular to permit this interpretation. If they are nodes they should show some indication of the phyllotaxy, but neither their spacing nor their arrangement shows any definite order. Furthermore, it is to be expected that some of them would show attached leaves or leaf-like appendages, but so far there exists but a single doubtful instance where anything that could possibly be interpreted as foliar appendages has been seen among the several hundred fossils that have been examined. Even in this solitary instance the attachment of these problematic appendages as the "nodes" is uncertain. Lastly, if these lines were the points of attachment of leaves they would have been, in all probability, circumscribing ridges on the stems and would have produced concavities in the shale rather than the reverse. If these markings represent nodes they must have been furrows in the bark of the original stem. Berry states that in his specimen the lines are composed of denser coaly material than the rest of the stem, but his photographs show clearly the same sort of structure as shown by the Antrim shale material.

The interpretation of these fossils as branches presents other serious difficulties. Berry cites a specimen in which a lateral branch has a diameter greater than the main stem. Other irregularities have been noted—as, for example, an abrupt narrowing of the branch without any indication of lateral branches coming off at that place. Another difficulty in interpretation lies in the fact that the coal layer is almost always of uniform thickness over the extent of the specimen and there is very little difference in the thickness of the coal regardless of the width. If these were woody axes (and *Callixylon* was woody) the coaly material would show as a lens-shaped mass in cross section, the thickness being somewhat proportional to the width. This condition, however, does not exist, and the thicker coal layers are not by any means always associated with the broader specimens.

Bearing in mind Seward's suggestion that these "nodes" might be shrinkage cracks, it is interesting to compare the fossils with woody material and other water-soaked plant débris to be found along shore lines where the accumulated vegetable matter is subjected to wave action and alternate wetting and drying. Figure 4 shows such a plant fragment recently found among the boulders along the shore of Lake Huron. The striking resemblance shown by the transverse cracks in this wood fragment to the "nodes" of the carbonized "stems" is obvious. Singularly enough, the similarity extends not only to the lateral extent of the cracks, but to their spacing as well, and were this fragment of vegetable débris to be fossilized under the same conditions which we postulate to have existed when the black shales were laid down it is likely that a similar fossil would result.

It is generally assumed that the Antrim shale and other shales of similar age, as the New Albany and Ohio, were deposited in a body of water of considerable extent, and the contained vegetable fossils represent material which had been transported for some considerable distance and subjected to prolonged weathering. It is conceivable that the larger logs would have been stranded in the shallow water near the shore line of the bays or inland lakes in which the bituminous material was being deposited. The partial submergence of these logs would be favorable for decay and disintegration by wave action. As strips of bark and partially decayed wood became dislodged they were able to float away, after which they sank and became imbedded in the accumulating black mud. The alternate soaking and drying to which these plant fragments would have been subjected would cause cracking in a manner similar to that shown in Figure 4. It seems, then, that these "node-bearing branches" in the black shales may be more correctly interpreted as carbonized strips of cracked bark or wood torn loose from stranded logs before fossilization.

The predominance of *Callixylon newberryi* as a forest tree during the period of deposition of the black shales is attested by the widespread occurrence of silicified wood of this species. In Ohio it is found in several localities, ranging from Lake Erie to the Ohio River. In Kentucky it has been reported from the New Albany

shale in the vicinity of Lebanon and from the Chattanooga shale near Mill Spring, in the Monticello quadrangle. In Indiana large trunks are abundant, though widely scattered, in the New Albany shale between New Albany and North Vernon. In Michigan silicified material has been found in the Antrim shale near Alpena, and was reported many years ago by Rominger[6] in other localities farther west. Large silicified trunks of *Callixylon* occur in the Woodford chert in Oklahoma, which is probably of the same age as the Antrim and New Albany. Specific determinations of the Oklahoma material have not been made.

[6] C. Rominger, "Black Shales of Michigan," *Geol. Surv. Mich.*, Vol. III (1873–76), pp. 63–67.

STUDIES FOR STUDENTS

EVALUATION OF BOUNDARIES IN THE MAPPING OF GLACIATED AREAS

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Illinois State Geological Survey Northwestern University

ABSTRACT

Little has been written concerning the field technique used in the detailed mapping of Pleistocene deposits and the relative values of the various types of boundaries thus established. In this paper the use of certain criteria in mapping the Wisconsin moraines of northeastern Illinois is described. A study of several types of glacial boundaries and the data on which they are based shows that these boundaries differ greatly in accuracy, depending in part on the inherent characteristics of the boundary and in part on the data available to and gathered by the field worker.

INTRODUCTION

In mapping glaciated areas, many questions arise as to what features should be shown on the map. By long usage and custom it is generally agreed that (1) all features due to a single glaciation should be grouped together and (2) these features, whether deposits of various types or the several distinctive topographic forms of drift, should be differentiated and delimited. Thus the distinctions on a map of a glaciated region are (1) distinctions based on time and (2) distinctions based on lithology, on topographic form, or on both. The belief, held by some, that all such boundaries are generalized and indefinite is not justified. Some bodies of drift grade into each other, but others are sharply divided and may be mapped accurately. It is shown in the following pages that the accuracy of mapping of any glacial boundary depends in part on the inherent characteristics of the boundary and in part on the quantity of data gathered by the field worker.

The examples of drift boundaries described are drawn from the Elgin and Geneva quadrangles in northeastern Illinois. These have been mapped in connection with work done by the Illinois State Geological Survey. The excellent quadrangle maps of the United States Geological Survey, with their contour interval of 10 feet,

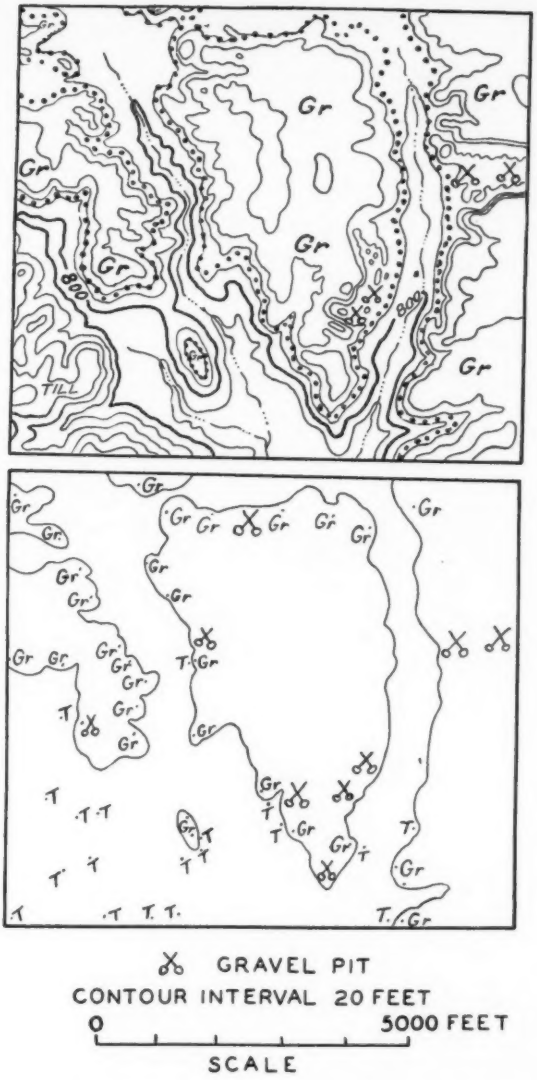
which were enlarged from a scale of 1:48,000 to a scale of 1:31,680, permitted mapping in detail, and it was possible to assign to each boundary a probable limit of error. The two quadrangles, which are entirely mantled by Wisconsin drift, lie west of the "Lake Michigan glacial lobe" in the area long ago designated by Leverett as the "composite morainic belt of northern Illinois."[1] The five morainic systems which occur in this area have a general north-south trend and range in age from Bloomington (oldest) on the west to Valparaiso (youngest) on the east. The glacial deposits are of diverse types.

The field objectives were: first, to determine the stratigraphy and types of drift materials; and, second, to determine the historical relations between the several drift sheets. The first objective was accomplished by a systematic study of exposures of drift in natural and artificial excavations, materials brought up by burrowing animals, location of springs and seepages, topographic forms, borings with a soil auger, and well logs. The age relations of the different bodies of drift were determined by tracing end moraines and eskers; by studying the superposition of deposits, peculiarities in color and composition of drift materials, and the profile of drift weathering; by recognizing terrace remnants at elevations appropriate to valley trains of known gradient; and by finding evidence of ice-held lakes and drainage changes or other physiographic relations that indicate the historical relations of the drifts. The effective use of these observations was greatly facilitated by the accurate large-scale topographic maps.

TYPES OF BOUNDARIES THAT MAY BE MAPPED FAIRLY ACCURATELY

Gravel overlying till.—Where a gravel formation overlies till or boulder clay the boundary between them may be mapped as accurately as the scale and contour interval of the map permit. Such an area, trenched by narrow valleys, is shown in Figure 1. Here the contact was traced throughout its whole length in the field by exposures of till and gravel and by the spring horizon and the topographic break in slope at the base of the gravel. The break in slope, which is not indicated on the topographic map but was plainly visible in the

[1] Frank Leverett, "Illinois Glacial Lobe," *U.S. Geol. Surv. Mon. 38* (1899).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field, is due to the fact that, under the same conditions, gravel generally maintains a steeper surface slope than boulder clay. The accuracy of this boundary as drawn is within 10 feet vertically (the contour interval) and is as accurate horizontally as are the contours on the map. In reproducing Figure 1 (upper figure), alternate contours on the original map were omitted; the lower figure shows the

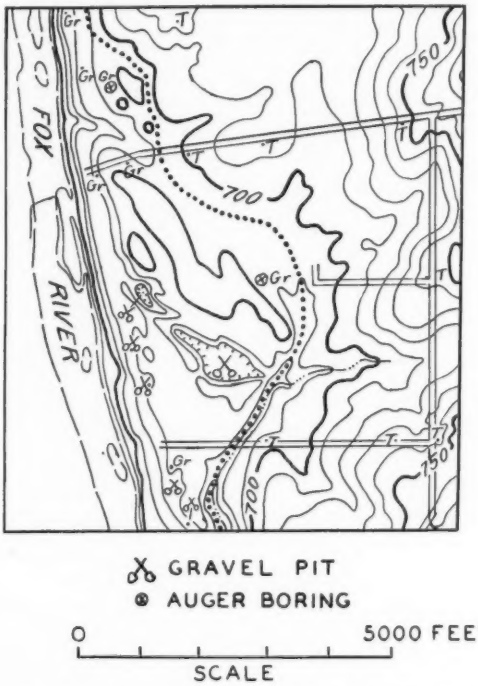

FIG. 2.—Map of gravel terrace (*Gr*) and till upland (*T*) east of North Aurora

distribution of the exposures of gravel and till and their relations to the mapped boundary.

Gravel terrace and upland.—The boundary between a gravel terrace and the upland behind it also permits accurate field mapping. It is commonly marked by a shallow trench or valley which in the area shown in Figure 2 is broad and poorly defined. After the suc-

cession of drift materials was determined at exposures and in auger borings, the center of this shallow depression was taken as the boundary line. Such a line is accurate only in so far as it is known (1) that the contours are correctly placed on the base map and (2) that the boundary follows the valley throughout its whole length. Thus the accuracy depends largely on the efforts of the field worker

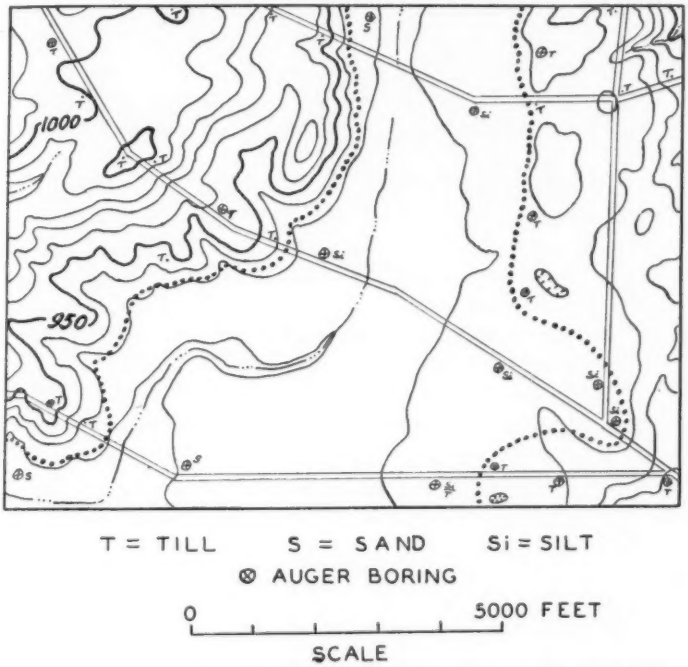

FIG. 3.—Map of lacustrine area bounded by moraines 2 miles northeast of Lily Lake

in finding outcrops and in boring holes. The boundary shown in Figure 2 is believed to be accurate within 250 feet horizontally.

Lacustrine deposits.—The margins of lacustrine flats which are underlain by silts differ greatly in the accuracy with which they may be mapped. A sharp topographic break on the west of a small lacustrine plain in the Geneva quadrangle permitted the boundary to be located as accurately as the scale of the map allows (Fig. 3).

After a few points on the boundary had been accurately established, it was drawn on the map at the determined elevation and is probably nowhere more than 250 feet from the true horizontal position. On the east, however, the lacustrine area grades into a low, flat moraine and here the boundary was located in part by the position of the contour lines representing the previously determined elevation of the lake flat and in part by borings with the soil auger. At one place the ice itself must have formed the lake barrier, and here the boundary could be located precisely only by numerous borings. As drawn it is necessarily generalized and its accuracy varies, but the error is probably nowhere more than 1,200 feet horizontally.

BOUNDARIES THAT ARE DIFFICULT TO MAP ACCURATELY

Gravel deposits.—Kames, eskers, and other gravelly features associated with moraines are difficult to map precisely. Generally the gravel is not confined to the sharp knolls and ridges, which are easily outlined, but is present also in the flatter intervening areas, which may, however, consist largely of boulder clay. In morainal areas underlain by gravel, auger borings are difficult to make and often give unsatisfactory results. Rarely can a field worker secure enough data to determine a boundary accurately. In practice, the boundaries are often drawn from an economic viewpoint and only areas that are believed to be a practical source for gravel are mapped as such. In the group of kames shown in Figure 4 (upper figure), the several areas are mapped as gravel because of the sharpness of their topographic forms and the known distribution of drift materials (lower figure). In the economic exploitation of such an area, it is probable that some gravel deposits will be uncovered outside of the places mapped, and that some of the materials in the mapped areas will, for one reason or another, prove not to be commercial gravel. Obviously the boundaries between gravel and till in such areas are sharp and not gradational, yet they are so intricate or concealed that it is difficult to map them accurately. It is not possible to assign to these boundaries a "limit of error" in the ordinary sense.

Moraines of different ages.—The moraines of these two quadrangles were differentiated on the basis of differences in their topographic forms and in the color and physical character of their tills. Be-

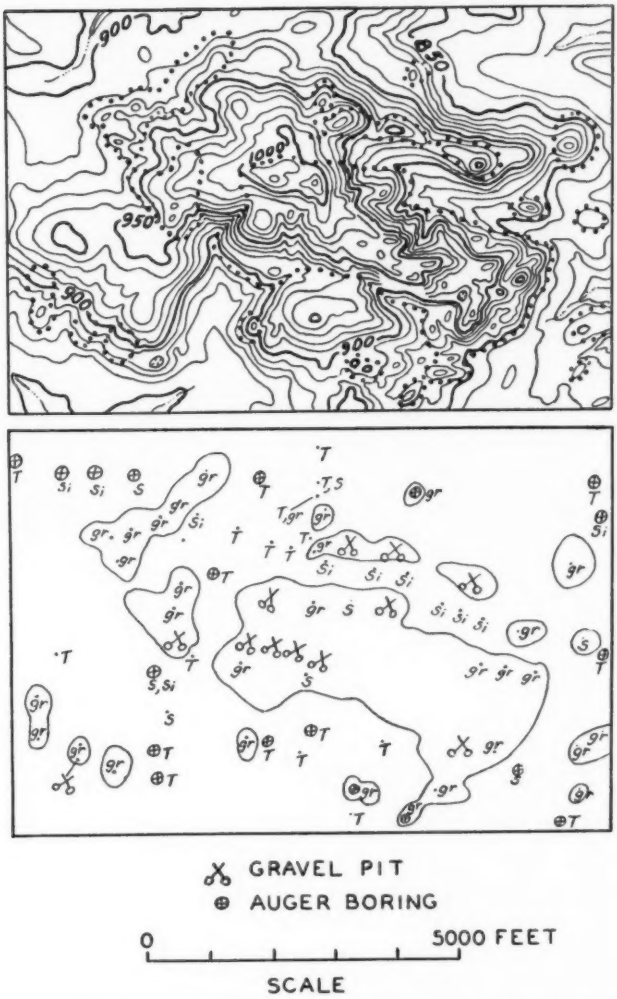

FIG. 4.—Map (upper figure) showing group of kames 2 miles southwest of Wasco. The kames are composed principally of gravel (*gr*) and sand (*s*), and are surrounded by till (*T*), silt (*Si*), and sand (*s*) as revealed by distribution of material in outcrops and auger borings (lower figure).

tween moraines thus clearly differentiated boundaries may be drawn with precision; but in places where two moraines come together and

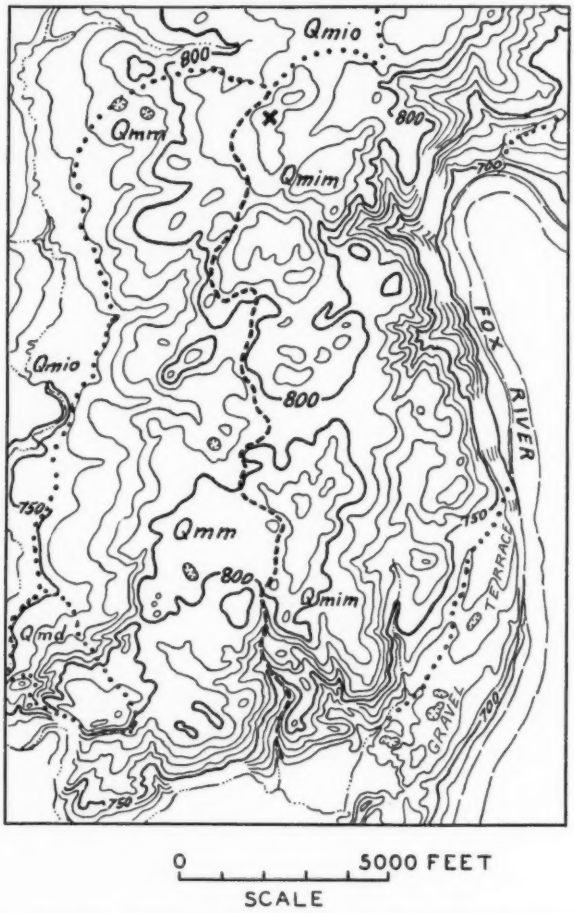

FIG. 5.—Map showing relations between Minooka moraine (*Qmim*), Minooka outwash (*Qmio*), Marseilles moraine (*Qmm*), Marseilles delta (*Qmd*), and gravel terrace.

have similar structure, color of materials, and topographic forms, it may be impossible to draw a definite line. In the latter instance,

fortunately rare in these quadrangles, difficulties arise as illustrated in Figure 5. The Minooka moraine (*Qmim*) is known to enter the area at the north, where it is flanked on the west by the outwash (*Qmio*) which buries a part of the Marseilles moraine (*Qmm*). From the south the Minooka moraine has been traced to a point just out-

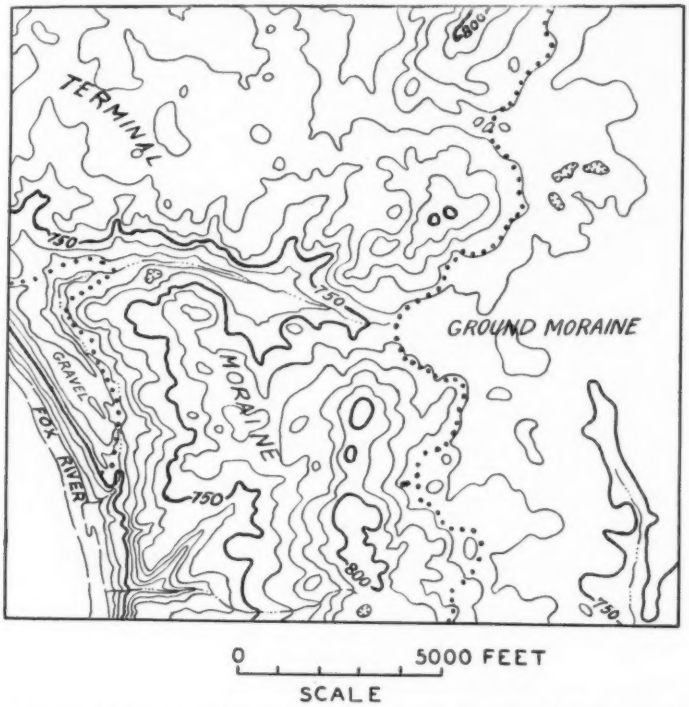

FIG. 6.—Map showing relations of Minooka terminal moraine and ground moraine east of St. Charles.

side of the southeast corner of the area shown in the figure. Within the area shown in Figure 5 it seems best to include in the Minooka moraine the large hill at the north marked *X*, because if the Minooka ice did not rest against this hill, outwash would have extended to the east of it. South from this hill the boundary is drawn to conform with the general north-south trend of the topographic forms. The po-

sition of this arbitrary boundary may be in error by as much as a half-mile. Here is a boundary between till sheets elsewhere differentiated, yet it cannot be mapped accurately for lack of evidence.

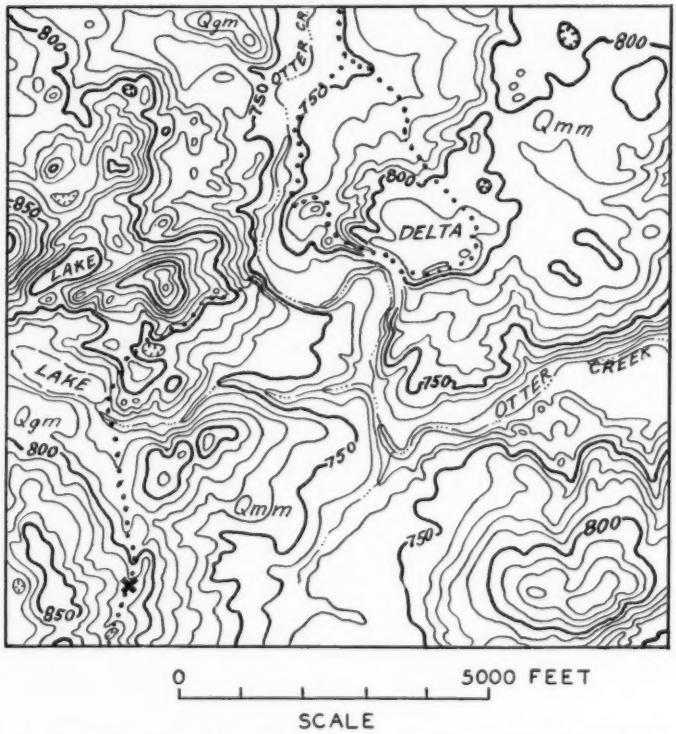

FIG. 7.—Map showing Marseilles delta, its relation to outer border of Marseilles moraine (*Qmm*), and relations between Gilberts moraine (*Qgm*) and Marseilles moraine 2 miles northwest of St. Charles. Other boundaries are omitted.

Terminal and ground moraine.—A terminal moraine and the ground moraine of the same glaciation are by definition gradational and not sharply differentiated. A portion of the Minooka "till ridge" and the Minooka ground moraine to the east of it are shown in Figure 6. In some regions ground and end moraines are reported to differ in composition, but in this area both are composed almost

wholly of boulder clay. The boundary, which was necessarily drawn in the field, is based only on topography and is intended as a median line between the low, subdued swells of the ground moraine and the higher forms of the till ridge. Its gradational character should be indicated on the published map.

Boundaries established by physiographic relationships.—General physiographic relations are often important in determining the age and extent of drift areas. For example, a broad north-south glacial valley, through approximately the center of the area, separates the Marseilles moraine on the east from a gravelly part of the Gilberts moraine on the west (Fig. 7). In this valley a delta, recognized as such by its materials and well-marked topographic form, slopes up to an ice-molded surface at the outer position of the ice which built the Marseilles moraine. The break in slope at the outer edge of this delta is 810 feet in altitude, and indicates clearly the ponding of waters to that level in the valley on the west and north. Such ponding could have occurred only if the Marseilles ice crossed the valley and rested against the Gilberts moraine up to an altitude of at least 810 feet. Subsequent search disclosed the two types of tills in adjoining road cuts at the point marked *X* farther south. Save at this point *X* and others still farther southwest, the boundary marking the western limit of the Marseilles drift southwest of the delta described above is wholly arbitrary, as no other criteria are available for its location.

CONCLUSIONS

The areas described above indicate that mapped boundaries of drift formations differ in accuracy. Some are as exact as the accuracy of the base map will permit, some are correct only within certain rather broad limits, and some are drawn arbitrarily where the data are insufficient to indicate their exact position. Where the relative value of the various boundaries is not indicated on maps of glacial deposits, or in an accompanying description, the user must form his own estimate of their relative worth.

DISCUSSION OF THE ORIGIN OF THE SUPPOSED METEORITE SCARS OF SOUTH CAROLINA

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U.S. Geological Survey

ABSTRACT

The low elliptical sand ridges in Horry County, South Carolina that were interpreted as meteorite scars by Melton and Schriever are believed to be beach ridges and bars in extinct lakes or lagoons, and to owe their uniform orientation to winds blowing from the ocean.

A reduced copy of a mosaic of aerial photographs covering most of the part of Horry County, South Carolina, that lies between the Atlantic Ocean and Waccamaw River has recently come into possession of the Geological Survey through the courtesy of Mr. J. D. Woodside, of New York. The area fronts the ocean for 20 miles, beginning at a point 10 miles from the North Carolina line, and extends inland a distance of $7\frac{1}{2}$ to $12\frac{1}{2}$ miles. The only town within this area is Myrtle Beach, a popular seaside resort. Part of the mosaic is shown in Figure 1.

The mosaic shows a number of remarkably symmetrical elliptical features, all with the longer axis pointed toward the northwest, that were tentatively called meteorite scars by Melton and Schriever.[1] The "scars" range in length from about $\frac{1}{4}$ mile to 2 miles. Each consists of an oval or elliptical more or less continuous ridge of light-colored sand lying within or enclosing a flat swampy area locally known as a bay.[2]

According to Melton and Schriever, who examined some of the ridges in the field, a typical ridge is 5 feet high and 250 feet wide. It is therefore not a conspicuous topographic feature as seen from the ground.

[1] F. A. Melton and William Schriever, "The Carolina 'Bays'—Are They Meteorite Scars?" *Jour. Geol.*, Vol. XLI (1933), pp. 52–66.

[2] The name "bay," as used in the Southeastern States for a tract of land containing an accumulation of humus, muck, or peat, is not restricted to the areas enclosed by elliptical sand bars, as might be inferred from the title of Melton and Schriever's paper, but is applied to swampy places of any size or shape.

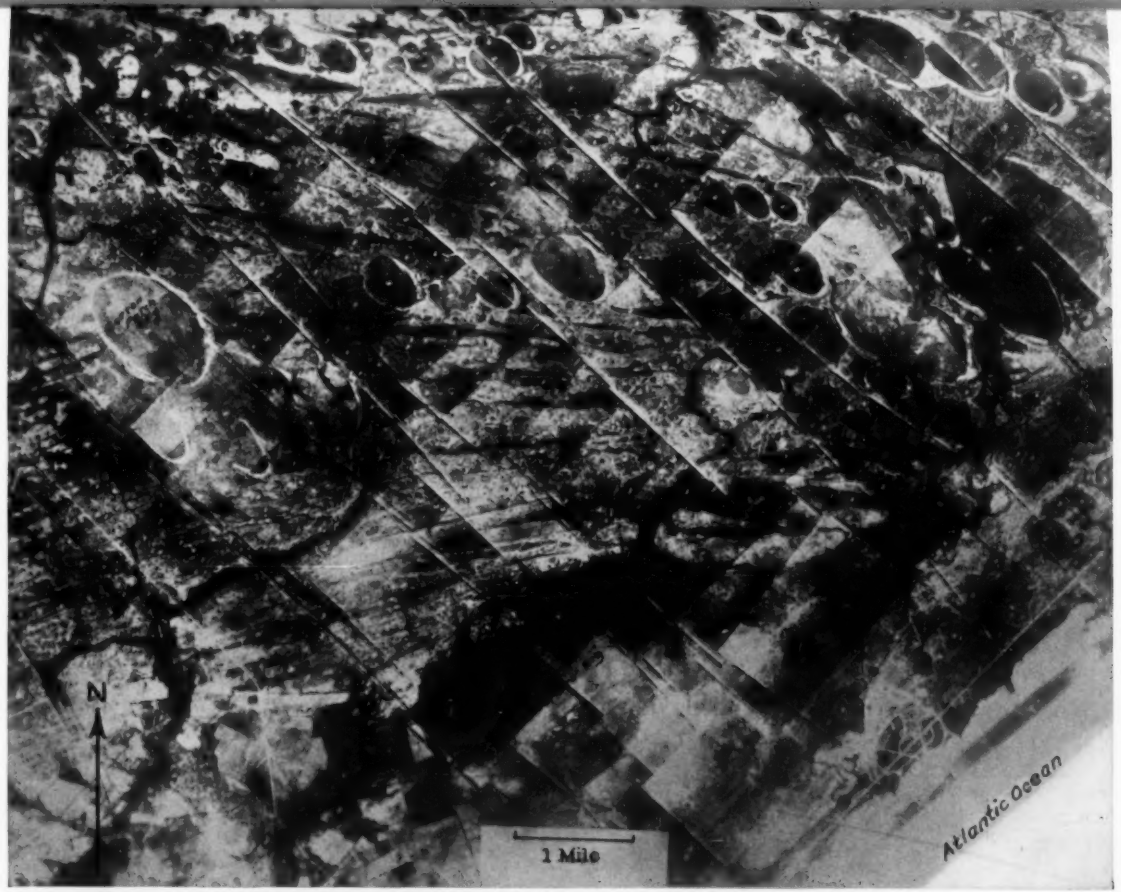

FIG. 1.—Mosaic of aerial photographs of an area north of Myrtle Beach, S.C.

Mention will be made here of three objections to the hypothesis that the elliptical "bays" in Horry County are scars made by meteorites. First, the ridges are too small. A meteorite big enough to leave a scar a mile wide might be expected to make a tremendous splash when it hit the earth. The rim around it would look like a mountain in the flat Carolina plain. Even granting that rims of various original sizes might have been eroded away or buried by sediments to such an extent that all now rise only about 5 feet above the plain, the rims around the big scars ought to be wider than those around the little scars; but this is not the case. If there is any constant difference in size, the smaller "bays" have wider and more conspicuous rims than the larger. Second, the scars from a shower of meteorites should be scattered haphazard throughout the region in which they occur; but there is a definite orderly arrangement of many of the elliptical ridges. The largest ellipses lie in rather compact groups within larger irregular "bays." The smaller ellipses lie end to end, like beads on a string. They have a distinct linear arrangement. Moreover, the direction of alinement of the ellipses of all sizes extends directly at right angles to the seashore—a coincidence that would be very unlikely if they were meteorite scars. Third, a cluster of meteorite scars ought to show no preference between upland and lowland; but all the elliptical "bays" appear to lie within lowlands that once were waterways.

One might raise other objections to the meteorite hypothesis, but it seems unnecessary to discuss more at length a hypothesis that calls for an extramundane visitor to explain topographic features that can be accounted for by the everyday processes of earth sculpture. In the writer's opinion, the elliptical sand ridges are bars and beaches built up in shallow lagoons or lakes by waves and currents set in motion by the wind.

Let us first consider the hypothetical steps by which a long narrow lagoon with sandy shores across which winds blow dominantly from one direction might be transformed into a chain of elliptical lakes. The wind would set up waves and currents that would scoop out hollows and build up points here and there along the shores. Each shore would thus become scalloped. The points on the windward side would continue to grow outward under the influence of the wind-

driven current and would gradually become bars extending into the lagoon in the direction of the wind. The return current would tend to carry sand away from the opposite shore and to build bars toward the wind. As the bars become longer and longer, the wind-driven currents would become more and more localized within their particular segments of the lagoon. If no strong tidal or river currents cross their ends, the bars eventually would cut the lagoon into a chain of lakes. Currents in a lake necessarily are rotary, for the water pushed constantly forward by the wind must flow back to its starting-point. Continued rotation of the water under the propulsion of the wind would fill in all re-entrant angles with sand and thus shape each lake into a more or less perfect ellipse or circle. The hypothetical stages here outlined are shown diagrammatically in Figure 2. The result of

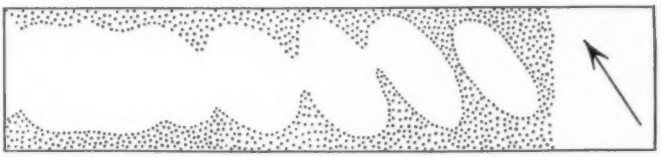

FIG. 2.—Stages in the change of a lagoon into a chain of lakes. The arrow indicates the direction of the wind.

some such process as this appears to be plainly shown in the three elliptical "bays" marked A on the map, Figure 3, which was traced from the mosaic; and the shores of many of the other "bays" in Figure 3 show the rounding effects of waves and currents.

The incomplete elliptical ridges that lie within large "bays" such as Lewis Ocean Bay and Cotton Patch Bay are probably also the work of waves and currents acting under somewhat different conditions. In this case, the hypothetical starting-point would be an irregular shallow lake or lagoon several miles in diameter. The winds and waves would build up piles of sand here and there within it and would gradually curve them into crescent-shaped keys, which were convex toward the wind. The water partly enclosed between a crescent-shaped key and an opposing shore or shoal would circulate under the force of the wind and might become completely enclosed by bars, thus forming a lake within a lake, like the lagoon within an

atoll in the ocean. *B*, in Figure 3, seems to be a crescent-shaped key such as has been postulated, and facing it is a curved bar that forms the other end of an incomplete ellipse.

Melton and Schriever[3] pointed out that the rims about the "meteorite scars" are highest at the southeastern ends. This may indicate that the prevailing wind came from the southeast; for the windward part of a sand key, being heaped up above water level by the

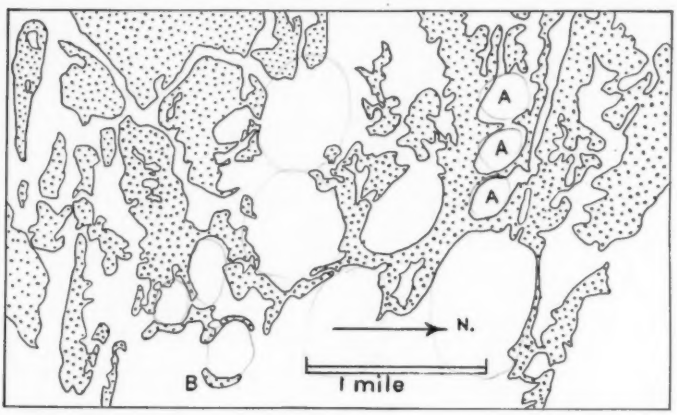

FIG. 3.—Map of an area north of Myrtle Beach, S.C. (see Fig. 4) traced from the aerial mosaic; shown also on Melton and Schriever's Fig. 2. Areas not stippled are "bays." *A*, *A*, and *A* are a chain of old lake beds partly surrounded by sand ridges; photographs of two of them are shown in Melton and Schriever's Fig. 1. *B* is a crescent-shaped key.

waves, is higher than bars built chiefly under water by currents. This explanation apparently would not apply to chains of ellipses formed by the segmentation of lagoons; but in that case the space between the rounded ends of the individual lakes and the original shore of the lagoon, being filled with sand, is the most conspicuous part of the rim, although not necessarily higher than the rest.

A conspicuous feature of the elliptical "bays" is their nearly perfect parallelism with one another. Their major axes all trend northwestward—a direction at right angles to the present seacoast. If the shores of the "bays" were shaped by wind-driven currents, the par-

[3] *Op. cit.*, p. 55.

allelism of their axes may record a constancy in the direction of the wind while they were being shaped. In both the hypothetical cases discussed above, one would expect the bars to be built either away from or toward the point from which the wind blows, and the longer axes of the resulting elliptical lakes would be parallel to one another and to the direction of the wind. The presumption is, therefore, that

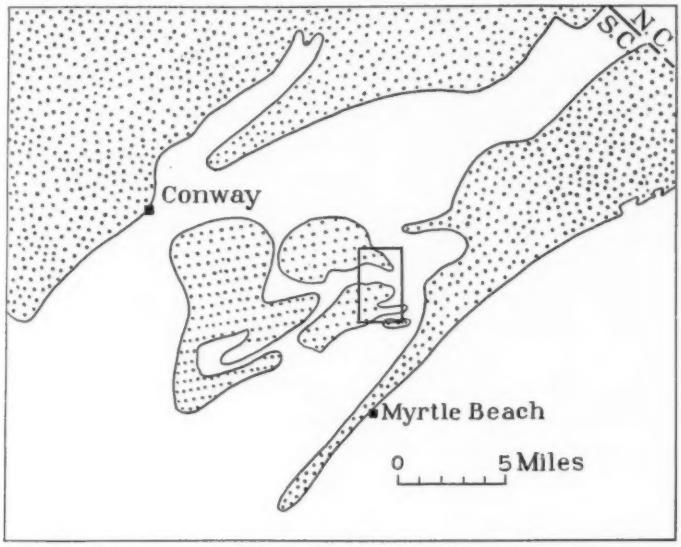

FIG. 4.—Sketch map of part of Horry County, S.C., during late Pamlico time, when sea level stood 25 feet higher than now. The so-called meteorite scars occupy the waterways between the islands. The waterways are much more numerous and intricate than shown. The small quadrangle shows the location of Fig. 3.

the wind blew either from the northwest or from the southeast. At the present time, however, as shown by records of the Weather Bureau at both Wilmington and Charleston, the prevailing winds along that part of the coast come from the southwest. But it is not improbable that the strongest storms blow from the ocean—that is, from the southeast.

The presence of lakes or lagoons is an essential condition postulated for the growth of elliptical sand ridges in the manner described.

That there once were lakes and lagoons in the coastal part of Horry County becomes evident upon study of the topography. The swampy "bays," around and within which rise the low sand ridges, evidently contained more water before they became clogged with vegetation. Inspection of the aerial mosaic reveals many long, narrow, shallow swales alternating with beach ridges that were evidently formed at a higher stage of the sea. The drainage pattern displayed by the mosaic map and by Figure 3, which is traced from part of it, retains many characteristics of tidal waterways. A map (Fig. 4) of the region as it was during the latter part of the Pamlico epoch of the Pleistocene, when sea level stood 25 feet higher than today,[4] shows that the seashore then occupied very nearly its present position, although the shore of the mainland lay north of Waccamaw River at Conway, which is now 14 miles inland. Part of the intervening area was occupied by a peninsula and a group of islands made up of a series of beach ridges and swales enclosing several large, irregular lagoons and a system of inland waterways. It is in these ancient lagoons and waterways that the elliptical sand ridges stand today.

At just what stage in the development of the region the elliptical sand ridges came into being is not now apparent. They may have been formed before the withdrawal of the sea, or they may have been formed later, after fresh water had replaced the salt or brackish water in the tidal channels. They must have been formed before the waterways became completely clogged with vegetation, or the currents that carried the sand could not have been set in motion by the wind.

The question naturally arises: Why are the ancient keys and linked ponds of Horry County more symmetrical than is customary for features of similar origin in other regions that have been investigated?

[4] The following papers by C. Wythe Cooke discuss changes of sea level during the Pleistocene: "Pleistocene Seashores, *Jour. Wash. Acad. Sci.*, Vol. XX (1930), pp. 389–95; "Correlation of Coastal Terraces," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 577–89; "Seven Coastal Terraces in the Southeastern States," *Jour. Wash. Acad. Sci.*, Vol. XXI (1931), pp. 503–13; "Tentative Correlation of the American Glacial Chronology with the Marine Time Scale," *ibid.*, Vol. XXII (1932), pp. 310–12; "Pleistocene Changes of Sea Level: (abstract)," *ibid.*, Vol. XXIII (1933), pp. 109–10, *Bull. Geol. Soc. Amer.*, Vol. XLIV (1933), pp. 177–78.

The answer may be that the winds blew more steadily there while the keys and ponds were growing; or perhaps they grew quickly during a hurricane. Perhaps they are not so rare as they are supposed to be. Glenn[5] has described similar features near Darlington, South Carolina, and called the ridges beach sand. These are prob-

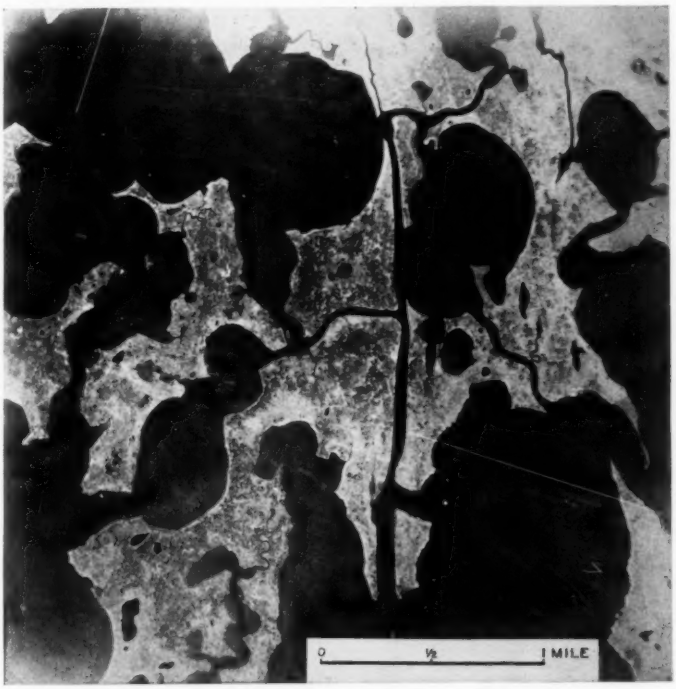

FIG. 5.—Aerial photograph of an area at the outer edge of the Mississippi Delta showing elliptical lakes similar to the "meteorite scars." Compare with Fig. 3.

ably on the Sunderland terrace. Sand Bay, $3\frac{1}{2}$ miles northwest of Kingstree, South Carolina (see soil map of Williamsburg County) is bordered by a ridge of clean, white sand resembling a beach. Sand Bay is on either the Talbot or the Penholoway terrace. The eastern side of an elliptical pond east of Blackville, South Carolina (shown

[5] L. C. Glenn, "Some Notes on Darlington (S.C.) 'Bays,' " *Sci.*, n.s., Vol. II (1895), pp. 472–75.

on the Williston and Bamberg quadrangles and on the soil map of Barnwell County) is blocked by a ridge of coarse white sand nearly a mile long and about 1,000 feet wide that rises 15 to 20 feet above the bottom of the pond. It, too, resembles a beach. This pond is on the shore of the Brandywine terrace, 270 feet above sea level. Land and water patterns like the rounded "bays" of Horry County are

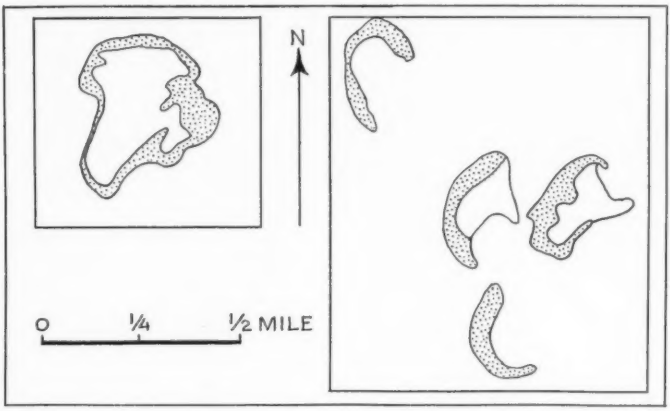

FIG. 6.—A sand atoll (left) and a group of crescent-shaped keys in Mosquito Lagoon, Fla. Traced from sheet T-4440-B of the Coast and Geodetic Survey.

forming today along the shore of the Gulf of Mexico near Galveston and at the outer edge of the Mississippi Delta. Figure 5, an aerial photograph of part of the coast of Louisiana, lacks only the bordering ridges to make it resemble the so-called meteorite scars of South Carolina. Sand atolls and crescent-shaped keys are common in the inland waterways of Florida. Some of those in Mosquito Lagoon are shown in Figure 6.

REPLY

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University of Oklahoma

Having proposed the meteoritic theory, the writer is eager to see it thoroughly tested.[1] It will be re-examined as disinterestedly as would any other hypothesis. Although Mr. Cooke's discussion and temperate criticism is welcome, it seems necessary to disagree with several of his statements of fact and with most of his interpretations.

All the facts which the writer has been able to gather concerning the elliptical basins on the coastal plain point to the existence of an isolated group of these features possessing a close agreement in shape as well as in alinement. The discovery of a single, elliptical basin in process of formation, from any cause whatever, does not necessarily demonstrate the origin of the elliptical bays, since one of their chief characteristics is the close agreement in shape among many such features. Likewise, the discovery of a number of elliptical basins of different orientations in process of formation does not necessarily demonstrate the origin of the bays, since one of the outstanding facts is a remarkable parallelism. Figure 5 of Mr. Cooke's paper illustrates features which are neither closed basins, smoothly elliptical in shape, nor parallel in alinement. They have thus no apparent relationship to the Carolina bays. Furthermore, they do not illustrate his theory, as there is no evidence that a bordering ridge or rim has been constructed. They do not appear to be due to wind or wave action. The author has examined an entire assemblage of vertical photographs from Barataria Bay, Louisiana, and has found no typical Carolina bays. Figure 5 appears to be from this locality.

Mr. Cooke is reasoning mainly from the topography visible on the Myrtle Beach mosaic, yet the total area in which elliptical Carolina bays occur is many times as great as that which has been photographed. Such a restricted outlook may lead one to false conclusions.

[1] F. A. Melton and William Schriever, "The Carolina 'Bays'—Are They Meteorite Scars?" *Jour. Geol.*, Vol. XLI (1933), pp. 52–66.

The writer is indebted to his friend and colleague, Dr. Schriever, for valued assistance during the field investigation and for helpful criticism during the preparation of this paper.

Then, too, near Myrtle Beach, the former action of waves and currents along an elevated shore has left many indications which are apparent upon the surface where the elliptical bays exist. Such overlapping processes may easily confuse an observer in his interpretation of the map.

RIMS

It is unquestionably true that the larger bays have the larger rims. They are longer, higher, and in general broader than the rims of the small bays. Many of those in the northeastern part of the mosaic are partly concealed by vegetation, so that they are not readily seen on the photographs. This may have led to Mr. Cooke's error regarding the size of rims.

According to his paper the bays exist only by virtue of crescent-shaped ridges. This is far from the truth. The basins exist as topographic depressions below the general level of the surrounding country, and well records indicate that in many cases the bays would be 10 to 25 feet deep if the recent increment of vegetation, its decayed products, and soil were removed. Large bays would probably be much deeper. In addition, the following facts show that the rim sand came from the basins, which they enclose. (1) Five miles southwestward from Florence, South Carolina, a sand pit in the rim of a prominent bay reveals a crude torrential bedding which dips about 10° directly away from the center. The beds are manifested by differences in size of grain. Use of a soil auger near Myrtle Beach revealed that fine sand in the outer part of a rim rests upon a coarse sand, which in turn appears at the same level in the surrounding surface. Most of the bays, however, and in particular those situated well up on the coastal plain, showed no structure at all. (2) The nice adjustment of rim size, as well as rim curvature to the shape of the bays, are additional proofs that the sand of the rim was derived from the basins themselves. Had it come from elsewhere and had it been moved toward the basins, there is no reason why it should have stopped just on the edge in the same fashion in the hundreds of bays which exist. The Carolina bays cannot be due entirely to the construction of rims and hence they cannot be segmented lagoons, unless these rims are as deeply rooted as the bottoms of the enclosed basins. Some obviously are not.

Were the peat and associated vegetable matter removed from a typical bay, it is estimated that the volume of the void thus created would be at least twenty-five times the volume of the rim. This amount of material must have been completely removed from the basins at the time of origin or subsequently. It is improbable that winds were the original excavating agent.[2] Moreover, since this material was moved predominantly southeastward, and since it is unlikely that tidal estuaries are competent to erode so persistently and systematically, one must conclude that this great difference in volume is incompatible with the lagoon and lake hypothesis. But for the seaward movement of rim material, the smooth beachlike profile would suggest that the rims have been constructed by ordinary beach processes. Such an anomalous condition leads one to consider the possibility of ocean-bottom currents a considerable distance offshore having been the chief transporting agent, and ordinary shore processes, at the time of emergence, a modifying agent.

ALINEMENT AND DISTRIBUTION

It is misleading to state that the bays are alined "directly at right angles to the seashore." Viewed regionally, it is true that from Cape Hatteras southward they are thus alined to the main trend of the *coast*. Yet even this generalization cannot be applied to the entire area, since in the suburbs of Norfolk, Virginia, two obscure, though unmistakable, bays were found with orientations of S. 47 E. and S. 55 E., whereas the coast trends S. 15 E. These bays are visible on mosaics made by the Army Air Corps. So far as data are available, it is thus seen that the prominent change in coastal direction at Cape Hatteras is not reflected in an altered alinement of the bays. Is it possible that during late Pliocene or Pleistocene time the coast continued its northeastward trend beyond Cape Hatteras? The answer must be sought by those familiar with the topography of the ocean bottom.

This northwest-southeast alinement of bays may be very significant. On the other hand, it may be only accidental, since in detail the *shore* changes its direction repeatedly as much as 90°—for example from Cape Romain to Cape Fear, from Cape Fear to Cape Lookout,

[2] *Op. cit.*, p. 61.

etc. The only undoubted elliptical bays thus far found near Cape Fear have the same orientation of long axes, within 2 or 3°, as do those 50 miles farther southwest; yet the shore has changed its direction by 70°. The shores of the Pleistocene marine terraces, as mapped by the North Carolina Geologic and Economic Survey,[3] change their directions as abruptly as the present shore. It thus seems impossible to say that the bays were alined in a fixed manner with respect to the shore at any time in their history.

Mr. Cooke has observed that one of the elliptical bays exists at an elevation of 270 feet above sea level. It is difficult to reconcile this with his statement that "all the elliptical bays appear to lie within lowlands that once were waterways." From Plate XIII[4] it is apparent that the main rivers which cross the coastal plain have been ocean waterways more than once during the marine invasions of the Pleistocene. Bays should be common along such lowlands if Mr. Cooke's contention is correct. They seem, however, to be entirely absent from the eroded valley slopes and flood plains, though they exist by the hundreds and perhaps by the thousands on the present uplands between these rivers. All the bays thus far seen on photographs and during flights from Raleigh to Savannah give no indication of having been genetically associated with the lagoons of the Atlantic shore. The existence of bays at various elevations from 20 feet above sea level near the coast to approximately 250 feet at a distance of 80 miles inland is not in harmony with the supposition that these features arose during a single hurricane. All could not have been at sea level at the same time. Furthermore, it appears that the rim sand has been moved chiefly seaward—not shoreward.

An aerial mosaic map of a large region must be assembled before positive statements can be made regarding distribution and pattern. As far as the writer has been able to observe, however, the pattern is a random one in respect to surficial processes.

Even in the area of the Myrtle Beach mosaic, it is misleading to say that the bays exist in the ancient lagoons and waterways, and are absent from the uplands. Indeed, it is doubtful if the islands shown in Mr. Cooke's Figure 4 were really islands in the Pamlico sea. The mosaic shows this area to be one of parallel curving beach

[3] Plate XIII of Vol. III (1912). [4] *Ibid.*

ridges concave toward the ocean. Their height, which is only slightly more than 25 feet above sea level, is appropriate to the belief that they originated from the shore processes in the Pamlico sea itself. These ridges overlap and interfere with each other in a way to suggest that they were built, with the help of waves, by shore currents moving northward. They were doubtless formerly tied to land on the south side of the embayment. Yet they now end abruptly above the lowlands of the Waccamaw River. This seems to indicate that the river valley has been eroded since the beach-ridge construction, whether this took place in Pamlico time or not. Though the valley may have been occupied by the sea at a later time, it could hardly have been an embayment of the Pamlico shore as indicated in Figure 4. An elliptical bay nearly a mile long, and others of smaller size are present among the beach ridges of this so-called island, where their presence seems to have interfered with ridge development. On the other hand, such bays are lacking on the valley slopes of this river as well as from those of other large rivers of the coastal plain. Perhaps their absence is due to the same cause—removal by erosion.

There are no bays in a low area of 11 square miles just back of the town of Myrtle Beach. This area is for the most part less than 20 feet in elevation and was undoubtedly below shallow sea water during Pamlico time; later it was probably a lagoon back of the barrier beach. The bays near Myrtle Beach appear to be absent from all surfaces which are below an elevation of about 15 feet.

METEORITIC HYPOTHESIS AND SUBMARINE SCOUR

Beds of coastal plain sediments in a number of cases seem to lie flat beneath the bay rims, yet they are above the level of the enclosed bay. Should this condition prove to be common it would be necessary, in order to retain the meteoritic hypothesis, to postulate widespread reduction of the original surface through marine planation. If the supposed scars had been filled with loose sand before the erosion began, it is conceivable that the drift of ocean water along the bottom would scour this fresh and less resistant sediment more effectively than it could remove the surrounding relatively hard material. Should these ocean-bottom currents move prevailingly seaward, crescent-shaped rims composed of the coarser-grained sediment

might thus be piled up around the southeastern ends of the filled basins. Aerial photographs have lately been made which show such lobate submarine bars convex seaward, just off shore near San Diego, California. In the western edge of Lake Tahoe similar features are seen. In both cases, however, no elliptical basin may be found; the crescent is complete in itself. While this modification of the original theory may help to explain some of the rims, it does not solve the problem of the elliptical basins. The meteoritic hypothesis would still remain the most plausible explanation even though the rims may have been formed at various times long after the bays developed.

A hypothesis of submarine scour operating upon pre-existing depressions in the weak sediments, might be adequate were it not for the remarkable parallelism of the elliptical bays and their total independence of the direction of the shore between Myrtle Beach and Wilmington. For example, irregular depressions might conceivably localize the scour on a shallow bottom and thus become elongated in the direction of prevailing bottom currents at the same time that a rim of relatively coarse sediment is being built, the finer material being swept entirely away. It seems more probable, on the other hand, that the original depressions would at once be filled with sediment. Bottom currents moving away from shore fall in the class of undertow; such currents should follow at least partially the slope of the bottom.

The three small *echelon* basins which have served as the type occurrence for Mr. Cooke's theory form a line which is parallel to the adjoining Pamlico beach ridges. It is no doubt this parallelism which suggested the idea that beach ridges have a causal relationship to the bays. The writer suggests, however, that the genetic relationship, if any exists, may be the reverse of that just stated. For example, if the rims were formed prior to the building of the Pamlico beach ridges, the most prominent ones were the highest features of the topography in their immediate vicinity. As elevations, they doubtless had an influence on the exact location of the shore of the old Pamlico embayment whose ridges we now see. At all events, an examination of the original mosaic will show that an unusual occurrence was chosen; probably it is an accidental one. The writer is of the opinion that he

has seen nearly all the aerial photographs ever made on the coastal plain between Dismal Swamp and the Savannah River. In the summer of 1932, at least, together with Schriever he examined all the available photographs in the possession of the U.S. Geological Survey, the U.S. Engineers, the Army Air Corps at Fort Bragg, North Carolina and at Langley Field, Virginia, not to mention views in the files of private photographic companies. If photographs can be found proving the existence of a definite pattern, they will constitute evidence of the first importance. If such do not exist it is believed that a chance arrangement has been exaggerated.

It is too much to say that other examples of the Carolina bays will not be found in the United States, but the author feels confident that no other large area exists. A sufficiently large section of the Atlantic coast has been photographed to permit one to state with assurance that bays are not now forming. Nothing similar has been found in the present lagoons, nor on the present barrier islands, nor even along the shore of the Carolinas themselves. During the past seven years the writer has examined a large number of aerial photographs from various parts of North America—chiefly coastal districts. Florida in particular has been well photographed in separate localities from the north end of the state to the south. Much of the coast of California south of San Francisco, a considerable part of southern and central Louisiana, as well as large areas of the coastal plain of Texas have been examined. Neither these districts, nor others in the interior have revealed features similar to the Carolina bays, though elliptical basins of various origins may be found. Only exceptionally are they very symmetrical, however, and never do they occur in parallel systems similar to this one. There is little weight to the assertion that elliptical bays exist in a certain region if aerial photographs are not available to substantiate the claim, for the uniqueness of the bays is of such a nature that they cannot readily be discerned from the ground.

Several criticisms of the proposed lagoon theory will merely be stated, discussion being left for another time. (1) If the narrow elongate swales which lie between the beach ridges are necessary for the development of small bays, why are the bays not found where these ridges and swales have their optimum development, i.e., just be-

tween Myrtle Beach and Conway? (2) The beach ridges of the Myrtle Beach mosaic change their directions by 60°, yet the bays with which they are associated maintain a closely parallel orientation. (3) Why should the bays, when traced seaward, disappear approximately at the inner border of those portions of the Pamlico terrace which obviously have been *constructed* by shore processes? (4) At the present time sea breezes are not effective in moving sand for more than 2 or 3 miles inland, and furthermore the direction of their effectiveness changes with the direction of the coast line. Farther inland the prevailing winds redistribute the rim sand toward the northeast, as is shown, for example, by the projecting points of sand in Figure 4 of the original paper.[5] (5) If the uniform plan of the bays is due to the action of swirling lake water under the influence of wind, why are depositional and erosional lakeshore features so generally absent? (6) The three *echelon* bays referred to by Mr. Cooke do not change gradually into an open lagoon or swale. (7) The theory does not offer an explanation for the mutual interference of bays, so commonly seen. (8) Why are elliptical bays absent from present shores?

Mr. Cooke realizes the necessity of inventing a process which could produce the uniform ellipticity and the remarkable parallelism, and this he has attempted to do. It is believed, however, that the proposed mechanism is too indefinite and moreover that it is totally inadequate to account for such systematic relationships, even in a district as small as that of the Myrtle Beach mosaic. The requirements are very exacting.

The reader must be the judge of the status of the meteoritic theory, and should give it no more credence than the facts will support. Without doubt much needs to be done to place the evidence itself upon a basis of certainty. For example, it has not yet been proved that the bays continue to maintain their parallel alinement over the entire area in which they exist. The writer, however, has been unable to find an important exception. If such should be found, it would be necessary to substitute another theory. This should probably involve submarine scour.

[5] Melton and Schriever, *op. cit.*

REVIEWS

(1) *Guide Book*, Sixth Annual Field Conference (1932), Kansas Geological Society. 8×11 in. Pp. 125; figs. 118; pls. 3; (2) *Geologic Cross Section from Western Missouri to Western Kansas Showing Detailed Correlation of Permian Big Blue Series and Pennsylvanian.* By BETTY KELLETT. Horizontal scale 5 mi. to 1 in.; vertical, 250 ft. to 1 in. Wichita: Kansas Geological Society, 1932. $10.00.

The field conferences sponsored by the Kansas Geological Society are coming to be ranked among the important annual meetings of professional geologists in the Central United States. The sixth conference was concerned mainly with the study of the Pennsylvanian and Permian formations in Kansas, Missouri, and Nebraska. The route traveled extended from Wichita, Kansas, east to Sedalia, Missouri, west to Junction City, Kansas, north into Nebraska, east to Falls City, north to Plattsmouth, and west to Lincoln, a total distance of nearly 1,100 miles.

The main part of the *Guide Book* is a detailed road log containing descriptions of all geologic phenomenon seen en route, oil fields, correlation tables, and items of geologic and historic interest. It is illustrated by strip maps of the route traveled and by detailed graphic sections with measurements and brief descriptions of the exposures seen at all stops.

The *Guide Book* also contains much valuable information, unavailable elsewhere, on the Pennsylvanian and Permian strata of this region. This is presented (1) in the graphic sections mentioned above; (2) in four papers that follow the detailed road log: "A Reclassification of the Pennsylvanian System in the Northern Mid-Continent Region," by R. C. Moore, pp. 79–97; "Brief Discussion of the Bronson Group in Kansas," J. M. Jewett, pp. 99–103; "Index to the Stratigraphy of Eastern Kansas and Adjoining Areas," by W. A. Ver Wiebe and W. R. Vickery, pp. 105–19; and "Outline of the Pennsylvanian of the Appalachian Region," by A. C. Bevan, pp. 121–24; and (3) in three folded maps: "Geological Map of Parts of Kansas and Nebraska," by R. C. Moore and G. E. Condra, 6 mi. to 1 in.; "Map Showing Areal Geology of the Pre-Chattanooga Surface in Northeastern Kansas (and Northwestern Missouri)," by J. V. Howell, 18 mi. to 1 in.; and "Map Showing Thickness of Cherokee (Shale)

in the Forrest City Basin," by F. G. Holl, 18 mi. to 1 in. The paper by Moore and the map by Moore and Condra are particularly noteworthy and will be of interest to all geologists concerned with Pennsylvanian stratigraphy.

The *Geologic Cross Section* by Miss Kellett extends from St. Clair County, Missouri, to Grove County, Kansas, a distance of about 400 miles and is based on the study of 138 drillings. Many of the smaller Pennsylvanian and Permian units as well as larger units of all ages from Pre-Cambrian to Tertiary are distinguished. This is a striking presentation of extensive subsurface studies and, in connection with Moore and Condra's geological map, gives an unrivaled three-dimensional picture of the Pennsylvanian and Permian systems in Kansas.

A table on the margin of the cross section presents Moore and Condra's revised classification of the Pennsylvanian and Lower Permian systems in Kansas and Nebraska, including certain changes in nomenclature made subsequent to the field conference.

J. MARVIN WELLER

Report of the Committee on Sedimentation, 1930–1932. (National Research Council Bulletin No. 89). Prepared under the auspices of the Division of Geology and Geography by W. H. TWENHOFEL, COMMITTEE MEMBERS, and OTHERS. November, 1932. Pp. 229. $1.00.

This two-year report, consisting of twenty-two separate reports, contains records of valuable original research by various investigators, and includes several useful bibliographic lists. The scope of the report can be appreciated by giving the Table of Contents:

(1) "Introduction," W. H. Twenhofel; (2) "The Classification and Terminology of the Pyroclastic Rocks," Chester K. Wentworth and Howel Williams; (3) "Recent Advances in the Study of Peat," W. E. Powers; (4) "Studies of Recent Marine Sediments Conducted by the American Petroleum Institute," Parker D. Trask; (5) "Experiments with the Settling of Bentonite in Water," Edward M. Kindle; (6) "The Relation of the Buffer Mechanism of Sea Water to the Solubility of Calcium Carbonate," D. M. Greenberg and E. G. Moberg; (7) "Notes on Investigations of Modern Marine Sediments in California," Thomas Wayland Vaughan; (8) "Bacterial and Chemical Factors in Lime Deposition at Tortugas, Florida," Haldane Gee; (9) "Report on Some Work on Sediments Done in Germany in 1931," Hans Becker; (10) "Varved Sediments," Ernest Antevs; (11) "Chert and Flint, Concretions, and Cone-in-Cone," W. A. Tarr; (12) "Sedimentation Studies at Stanford University," Eliot Blackwelder; (13)

"Study of the Abrasional Work of River Ice and of Glaciers," Chester K. Wentworth; (14) "Chemical Papers Bearing on Sedimentation," George Steiger; (15) "Some Recent Applications of Physics to Sedimentation Problems," C. E. Van Orstrand; (16) "Investigations in Ground Water Hydrology that Bear on Sedimentation," Arthur M. Piper; (17) "Research on Sediments by British Scientists during 1930–1932," Henry B. Milner; (18) "Recent Studies with Reference to the Rôle of Microörganisms in Sediments," George A. Thiel; (19) "Accessory minerals of Crystalline Rocks," Alexander N. Winchell, E. S. Larsen, J. C. Reed, J. T. Stark, A. C. Tester, and J. F. Wright; (20) "Abstracts of Literature on Accessory Minerals of Igneous Rocks," J. C. Reed; (21) "Abstracts of Literature on Accessory Minerals in Sedimentary Rocks as Related to Possible Source Crystalline Rocks," Allen C. Tester; (22) "Studies in Glacial Sediments, 1930 and 1931," M. M. Leighton and Enid Townley.

This report, now appearing as a bulletin of the National Research Council and containing results of original researches, illustrated by photographs and drawings, has become more than a committee report. It is, in reality, a scientific journal which is indispensable to students of sedimentology.

F. J. P.

Stratigraphy of Plains of Southern Alberta. A Symposium. Fourteen papers by members of the Alberta Society of Petroleum Geologists and the American Association of Petroleum Geologists. Published by the American Association of Petroleum Geologists, Tulsa, Oklahoma, 1931. Pp. 163; figs. 56.

This symposium gives the latest and most comprehensive descriptions and correlations of the Cretaceous rocks of northern Montana and southern Alberta. To a large extent it corrects in the light of present knowledge the somewhat disorderly stratigraphic nomenclature for this district. In so doing the symposium performs a useful service, because the strata deposited in the advancing Upper Cretaceous sea have long presented problems to geologists working in the Rocky Mountain tract owing to the variations in contemporaneous sedimentation and to deposition of lithologically similar formations along the line of the epeiric advance. Clearing up some of this confusion the symposium shows:

The marine readvance of Upper Cretaceous time is represented in the Montana–southern Alberta region by the Blairmore and its underlying conglomerate. Lying conformably upon the Blairmore is the Blackleaf shale member, heretofore often considered as part of the overlying Colorado shale. Other workers have held the view that the Blairmore and the

Blackleaf together constitute the local equivalent of the Dakota sandstone. The symposium discourages the term "Dakota" which, as many believe, has too often been used as a "catch-all." The strata exposed at Great Falls, Montana, should be called Blairmore rather than Kootenai. It is noteworthy that the paleobotanical evidence according to Berry and Buckman would place the Comanchean-Cretaceous break within the Blairmore. If, as seems proper to the reviewer, Upper Cretaceous time begins with the first spreading of the Gulf sea northward, the floral change would seem to be given undue importance.

The Pierre group, overlying the Colorado shale, comprises a series whose interfingerings and variations from place to place bear witness to oscillatory conditions of sedimentation. Milk River formation, lowest of the group, has been said to be lithologically equivalent to Eagle, Virgelle, Hygiene of Colorado, lower Two Medicene and probably Shannon of Wyoming. Pakowki is the name chosen for the formation which in 1905 was correlated with the Claggett beds. In the eastern part of this region the Pakowki constitutes a considerable portion of the Pierre group; westerly it fingers out; in places it has not been possible to distinguish the Pakowki from strata interfingering beneath the Milk River formation. The Foremost formation and Pale beds are difficult of separation yet seem sufficiently different to require distinct designations. Uppermost of the Pierre group, the Bearpaw marine shale is also known as the Lewis shale of Wyoming.

The Fox Hills sandstone, occurring in Alberta, the Dakotas, and Colorado, records the final deposition of the Montana seas and is, because of its wide distribution, the best horizon marker in the Cretaceous system.

The St. Mary River formation is defined as the continental deposits between the marine and brackish-water Fox Hills below and the Willow Creek formation above, although it is stated that Lance seems to be a satisfactory term to apply to these strata of the northern Cordilleran region.

RANDALL WRIGHT

An Introduction to Geology. By WILLIAM BERRYMAN SCOTT. 3d ed. 2 vols. New York City: Macmillan Co., 1932. Pp. xii+1089; figs. 391.

This new edition is such as only a scholar like Professor Scott with his broad knowledge and his wealth of experience in field work, in research, and in teaching could produce. Very much of the old material has been rewritten and is combined with a clear summary of the latest researches along a great variety of lines. This includes a brief discussion of various

geologic and biologic hypotheses. There are many new figures which illustrate the thoughts to be conveyed most clearly and forciby. As in the previous editions the author has emphasized the geology of North America. He has, however, extended somewhat his discussions and illustrations of the other continents. This was necessary in order to summarize the principal contributions which have enlarged the knowledge of their geology during the twenty-five years since the publication of the last edition.

Because of the amount of new material added, the third edition is issued in two volumes and with a larger page size. In *Physical Geology*, Volume I, the material has been rearranged. Igneous rocks, vulcanism, and earthquakes are placed in neighboring chapters and their treatment has been considerably extended both in text and illustrations. The volume begins with an interesting chapter on the larger features of the earth, and some of the hypotheses accounting for them. Then follow in succession chapters on rock-forming minerals, the igneous rocks, vulcanism, and earthquakes, the action of the surface agencies—ground-water, rivers, ice, organisms, and ocean. Next is considered the structure of the stratified rocks—folds, faults, joints, and origin of mountain ranges. The volume concludes with chapters on metamorphism, ore deposits, and land sculpture.

In Volume II, *Historical Geology*, the succession of chapters is the same as in the previous edition, but all topics have been brought up to date and many new facts have been added, especially as to the origin and migration of mammals and the various groups of plants. The new illustrations here include restorations of groups of vertebrates by the well-known artists, C. R. Knight and R. B. Horsfall.

This new edition is a very welcome addition to the series of textbooks so essential to students in cultural, pure, and applied geology.

HERVEY W. SHIMER

Mineraljordarternas Fysikaliska Egenskaper [The Physical Properties of the Mineral Soils]. By THORD BRENNER. Bulletin de la Commission Géologique de Finlande, Nr. 94. Helsingfors, 1931. Pp. 164; figs. 22.

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The author has summarized the results of ten years' work as geologist of the Geotechnic Bureau of the Board of Railway Directors in Finland. The report reveals an interesting study of the strength and supporting capacity of different soils and sediments. An understanding of the principles involved is important for the construction of railroads and buildings. The work should be of interest especially to engineering geologists, soil technologists, and sedimentologists.

H. W.

La Estructura Geológica de la Cordillera Argentina entre el Río Grande y el Río Diamante en el sud de la Provincia de Mendoza. By Enrique Gerth. Actas de la Acad. Nac. de Ciencias de la Republica Argentina. Vol. X. Buenos Aires, 1931. Pp. 123–72; figs. 16; structure sections, colored map.

This contribution merits study because of the association of various igneous rocks with extremely complex structures produced during several episodes of Andean orogeny.

An old pre-Andean basement of granites and keratophyres is overlain by Mesozoic rocks comprising the Lias, Dogger, and Malm formations.

These strata were deformed by easterly directed stresses producing north-northeast trending folds and overthrust faults. Deformation was most severe in the western part of the area. Dr. Gerth has recognized three periods of folding which have taken place in Upper Cretaceous, early Tertiary, and later Tertiary times. He has also differentiated various types of folding based upon the depth of the deformation. The first or "primary" order has arched Lias and Lower Dogger formations into broad folds in which the pre-Andean basement has also been involved. The second order of folding, which occurred later, caused surficial deformation, with imbricated structures, which affected the Middle Dogger and Malm formations without deforming the pre-Andean basement. Considerable uplifting of the region came later and was followed by extensive volcanic activity.

Throughout the map area the complexity of the igneous occurrences is astonishing. From west to east five zones of intrusives have been differentiated and each appears to be definitely related to a phase of deformation. The intrusions are elongated in a north-south direction and mostly outcrop within anticlines in areas where overthrusting is absent. In addition to these zones of intrusions are Paleozoic granites, Triassic effusives and intrusives, and Jurassic and Cretaceous porphyries.

C. M. LANGTON

The Geology of Ceylon. By FRANK DAWSON ADAMS. National Research Council of Canada, 1929. Pp. 87; pls. 9; colored map 1.

This account of the geology of Ceylon is enjoyable reading for its historical and literary value as well as for its geologic information. Previous English accounts of this island have dealt principally with the graphite deposits and gem workings, and while the author does not slight these, he devotes most of his account to the physiography, structure, petrography, and stratigraphy of the island, bringing out much information that is new or which has been known only to local workers.

Although the Recent, Pleistocene, Miocene, and Jurassic are stratigraphically represented, the island is almost entirely composed of pre-Cambrian rocks. Discussion of these older crystallines fills much of the volume. Ceylon has apparently undergone domal uplift and this action seems to be continuing with sufficient activity to prevent the formation of fringing coral reefs. Three clearly defined peneplains are evidence of as many consecutive uplifts.

J. T. McC.

PUBLICATIONS RECEIVED

Illinois Mineral Industry in 1932. By W. H. Voxkuil and Alma R. Sweeny. State of Illinois Department of Registration and Education. Urbana, Illinois, 1933.

International Ice Observation and Ice Patrol Service in the North Atlantic Ocean. Season of 1932. U.S. Treasury Department Coast Guard, Bulletin No. 22. Washington: U.S. Government Printing Office, 1933.

Late Permian Brachiopoda of Southwestern China, Part II. By T. K. Huang. From Palaeontologia Sinica. Peiping: Geological Survey of China, 1933.

Lower Triassic Cephalopoda of South China. By C. C. Tien. From Palaeontologia Sinica. Peiping: Geological Survey of China, 1933.

Note on Computation of Density of Sea-Water and on Corrections for Deep-Sea Reversing-Thermometers. By C. C. Ennis. Department of Terrestrial Magnetism, Carnegie Institution, Washington, D.C.

Note on the Geology of Nanga Parbat (Mt. Diamir), and Adjoining Portions of Chilas, Gilgit District, Kashmir. By D. N. Wadia. Records of the Geological Survey of India, Vol. LXVI, 1932.

Occurrence and Physical Properties of North Carolina Marble. Bulletin No. 5. By Jasper L. Stuckey and James Fontaine. North Carolina State College of Agriculture and Engineering. 1933.

The Permian Yellow Sands of North-East England. By M. B. Hodge. From Proceedings of the University of Durham Philosophical Society, Vol. VIII, Part 5. Newcastle upon Tyne: T. and G. Allan.

Preservation of Natural Monuments in Japan, II. Tokyo: Department of Education, 1933.

The Preservation of Plant Tissues in Coal. By H. G. A. Hickling and C. E. Marshall. Proceedings of the University of Durham Philosophical Society, Vol. IX, Part 2. Newcastle upon Tyne: T. and G. Allan.

Les progrès de nos connaissances sur la géologie de la Mongolie. By Dr. R. Berbrugge. Anvers: Burton, 1933.

Scientific Results of the "Nautilus" Expedition, 1931, Parts IV and V. By B. Villinger and Henry C. Stetson. Cambridge, Massachusetts: June, 1933.

Skrifter Om Svalbard Og Ishavet, 1931. Oslo: Kommisjon Hos Jacob Dybwad.

Les Sondages electriques. By E. M. Poldini. Lausanne: F. Rouge & Co., 1932.

Tanganyika Territory Geological Survey Annual Report, 1932. Dar es Salaam: Government Printer, 1933.

Thermal Springs of Virginia. By Frank Reeves. Virginia Geological Survey, Bulletin 36. University, Virginia, 1932.

Transactions of the American Geophysical Union, Fourteenth Annual Meeting, April 27, 28, 29, 1933, Washington, D.C. Washington, D.C.: The National Research Council of the National Academy of Sciences, 1933.

Variations in the Quality of Amosite Asbestos at Penge, Transvaal. By Leopold Reinecke and Leslie McClure. From Transactions of the Geological Society of S. Africa, Vol. XXVI, 1933.